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THESIS

MINE/COUNTERMINE BASIS OF ISSUE
OPTIMIZATION PLAN

by

Thomas D. Pijor

June 1988

Thesis Advisor: Samuel H. Parry

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This thesis presents a high resolution stochastically based simulation to be used in the evaluation of measures of effectiveness to determine the optimal basis of issue of mine/countermine equipment. A discussion of the types of breaching equipment and the tactics involved is used to provide background for the simulation.

Several measures of effectiveness are used to determine how the various configurations of breaching equipment affect the battle and battle outcome.

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Mine/Countermine Basis of Issue Optimization Plan

by

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B.S., United States Military Academy, 1978

Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

The mobility and effective employment of tanks in a future conflict may be seriously threatened by enemy land mines.

This thesis presents a high resolution stochastically based simulation to be used in the evaluation of measures of effectiveness to determine the optimal basis of issue of mine/countermine equipment. A discussion of the types of breaching equipment and the tactics involved is used to provide background for the simulation.

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The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A. BACKGROUND

The United States Army currently possesses the most advanced tank in the world, the M1 Main Battle Tank. It is able to move faster, shoot more accurately, and maneuver better than any comparable system. Yet the emphasis on mobility and the high degree of technical sophistication which we have placed on the M1 may be negated by even a World War II vintage anti-tank mine. The use and effectiveness of landmines against tanks have substantially increased since World War I, while our ability to counter the landmine threat has not changed dramatically in the last 40 years. Proponency disagreements appear to have hindered the thorough formulation and development of a comprehensive mine clearing system while the search for and development of one device that would effectively perform all countermine functions has been understandably futile.

While there have been substantial advances in the development of new types of mines and minelaying equipment, the methods of detecting and clearing mines still leave much to be desired [Ref. 1]. There are still very few mine detectors which will detect nonmetallic mines, the most likely type to be found on the battlefield today. Once the mines have been detected they must be cleared or bypassed. The United States has been developing several systems to enable units to breach complex obstacles. Two of these are the track width mine plow (TWMP) and the track width mine roller (TWMR). Both the plow and the roller have inherent strengths and weaknesses, and neither of them is totally effective.

B. PURPOSE AND GOALS

Although detailed combat models (such as JANUS or CASTFOREM) are heavily used at the tactical level, some analysts and users have doubts about the use of this kind of model when evaluating the impact of a new piece of equipment entering the inventory. Detailed combat models are costly to build, costly to run, are quite demanding in data base requirements, not easily modified, essentially impossible to use for sensitivity analysis and other parametric studies, and not easily communicated to decision makers.

On the other hand, a model can be built rather quickly and inexpensively in order to answer questions of a particular nature. The model is written with specific goals in mind and specific output desired. Development of that type of model is the subject of this thesis. It examines various mixes of the TWMP and the TWMR with the goal of determining the optimal type and number of systems that can effectively be used to breach a series of minefields by an armor battalion. The countermine mix must provide effective mine neutralization in the breached lanes for the assault with minimum loss of momentum and time, and minimize breaching and assault force losses due to mine detonations.

By constructing the model in this fashion, the number of variables that could impact on the output is kept to a minimum and the output and analysis will provide results with an acceptable degree of accuracy.

C. METHODOLOGY

Through the use of a high resolution combat simulation using clearing and survivability data, output is generated which is analyzed and then evaluated under various measures of effectiveness which have been developed to provide comparisons between different force and equipment configurations. Figure 1 demonstrates the process by which the evaluation will take place. Entering the configuration or inventory, the minefield parameters and enemy actions, and the assault force's actions and decisions into the simulation model results in an exiting vehicle inventory, transit times and unit status codes which are then used to evaluate the desired measures of effectiveness.

In Chapter 2, the Concepts of Mobility and Operations are discussed. Additionally, a discussion of the options available to a unit commander in countering are examined in detail. The characteristics of the breaching equipment, Functional Simulation and Analysis Model

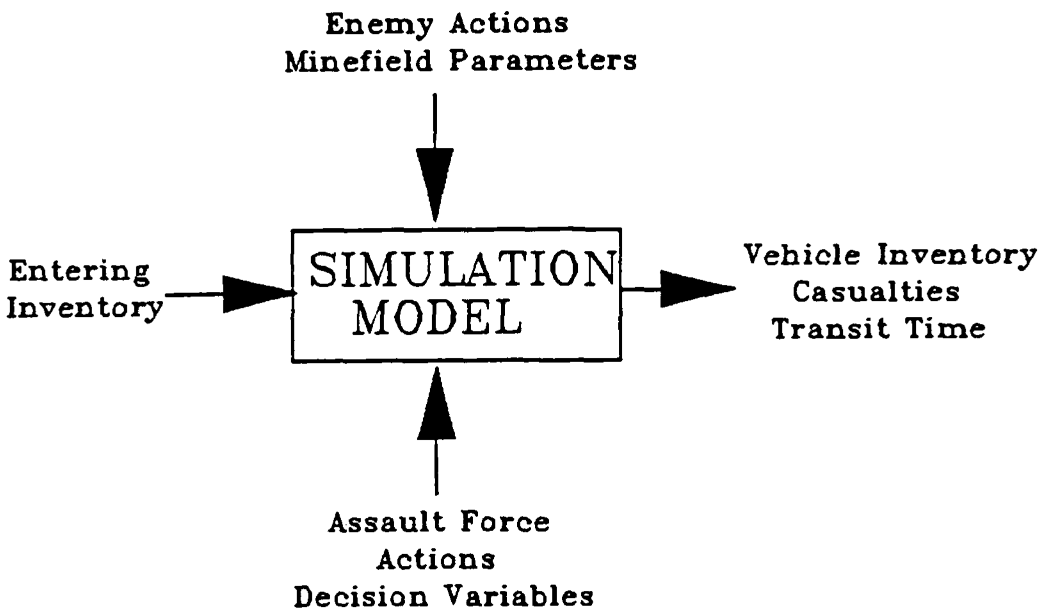


Figure 1. Functional Simulation and Analysis Model

their normal employment and the development of the measures of effectiveness used to analyze the output from the simulation are examined.

In Chapter 3, the layout and flow of the simulation are discussed, along with detailed descriptions of the various modules that compose the model. The tactical scenario which was used in the model development and simulation is included.

Chapter 4 deals with the output analysis and evaluation of the measures of effectiveness used to determine the optimal force structure.

Finally, Chapter 5 provides recommendations for possible future enhancements to the model as well as possible utilizations of this model and other models of this type. In the appendices, variables used in the simulation are defined, the computer code is listed and described in detail, and the data files used in the simulation are presented.

II. NATURE OF THE COUNTERMINE PROBLEM

A. CONCEPT OF OPERATIONS AND MOBILITY

Mobility is oriented toward reducing or negating the effects of existing or reinforcing obstacles to improve movement of maneuver/fire units and movement of critical supplies [Ref. 2].

The concentration of forces and weapons at the critical time and place is a prerequisite for winning both offensive and defensive battles. The firepower and cross-country mobility offered by tanks make them the most important conventional battlefield weapon of today and the future. The overall mobility of the forces may be countered through the use of existing and reinforcing obstacles. Existing obstacles may be considered to be those natural or man made obstacles which currently exist on the battlefield. Reinforcing obstacles are specifically designed to impede the movement of enemy units and are constructed when possible to complement existing obstacles, friendly fires, and scheme of maneuver.

Obstacles are intended to be employed in depth along the expected enemy axis of advance with the intent of stopping, delaying, or redirecting enemy tanks to a location advantageous to the employment of anti-tank weapons. If the obstacles are properly employed they are likely to delay an enemy unit attempting to pass through them. A delay that occurs within the range of anti-tank weapons covering the obstacles is likely to significantly increase the effectiveness of those antitank weapons. The primary purpose of obstacles is to enhance the effectiveness of friendly fires, to delay or disrupt enemy formations, to allow the tactical commander to use economy of force, and to enable him to protect his flanks.

The Soviet Army places great emphasis on landmine warfare, and they possess rapid and effective means of both laying and breaching minefields. They are likely to use mines extensively in defensive and offensive operations. By doctrine, their minefields are located at the front of defensive positions and are covered by antitank and general supporting fires. Soviet minefields are employed to disrupt the enemy attack by causing vehicle casualties, reducing overall momentum of the attack, and forcing the enemy into confined areas. Minefields located within the main area of defense are employed to provide kill zones for anti-tank weapons and restrict enemy movement to designated areas where the concentrated fires of all weapons are focused on the attacking forces. They are not used with the idea of blocking or destroying the enemy force, but to reinforce natural obstacles, scare the enemy, divert his attention from the defender and influence his maneuver. [Ref. 3]

Mines are widely recognized as the most effective reinforcing obstacle. While other obstacles can only act passively on tanks, mines have proven themselves to be capable of destroying tanks by themselves. The achievement during the combined employment of anti-tank weapons and anti-tank mines of a greater number of casualties than would be possible by summing the casualty producing capabilities of each acting independently is commonly acknowledged and is referred to as a synergistic effect.

To counter this threat of decreased mobility, tank mounted countermine sets of plows and rollers will give a tank company limited capability to conduct hasty minefield breaches. The countermine mix must provide accurate identification of minefield encounters, provide effective mine neutralization in the breached lanes, provide lanes for the assault force with minimum loss of momentum and time, and minimize breaching and assault forces losses due to mine detonations [Ref. 4].

The roller/plow team has distinct limitations. The roller, by virtue of the fact that it always travels in contact with the ground, is constantly detecting and clearing a path immediately in front of the vehicle on which it is mounted [Ref. 4]. However, due to the weight of the device, the breaching vehicle's mobility is greatly reduced. Additionally, due to the roller's method of neutralizing mines by detonation, it cannot withstand the rigors of constant breaching operations. The mine plows are not designed to detect mines but to clear a path directly in front of the plow tank once a minefield is encountered/ detected. Since the plow tank travels with the plow in the raised mode, the crew of the plow tank must be able to visually detect the minefield in order to determine when to employ the plow [Ref. 4].

B. TACTICAL RESPONSES TO MINEFIELDS

The offensive force commander must keep one principle in mind when a minefield is encountered: maintain the momentum of the offense. Obstacles must not stop or impede the movement for unusually long periods of time. The tactical commander has three alternatives when faced by an obstacle; he may breach, bypass, or "force through" the obstacle [Ref. 5].

1. The Bypass

To conserve time and manpower, obstacles are bypassed whenever possible. However, if the enemy has employed the obstacles properly, they will be difficult to bypass. [Ref. 6]

2. The Breach

A breach is conducted when the unit possesses the proper equipment to breach. Two methods of breaching may be employed: the assault breach or the deliberate breach. [Ref. 6] We are concerned only with the assault breach. The assault/hasty breach is done quickly during either a hasty or deliberate attack. The main objective is speed in gaining the breach, since delays may be costly in terms of casualties due to direct fires covering the obstacle. With the mineplow and mineroller, it maybe quicker and easier to attempt a breach than to bypass.

3. The Force Through

The "force through" or "bull" tactic is attempted when no other way to overcome the obstacle exists. The unit does not possess any breaching equipment and will drive through the minefield in hopes of clearing a path. Heavy losses are expected when this tactic is employed. [Ref. 7]

C. TYPES OF BREACHING EQUIPMENT

The track width mine roller (TRMR) is a 10 ton assembly consisting of two banks of rollers. The rollers detect mines by detonating them as it rolls over them. There is a dog bone and chain assembly between the two banks of rollers to activate any tilt rod mines which could cause a belly kill on the breaching vehicle. [Ref. 6] Mine rollers have the potential to provide countermine detection and neutralization only as long as the single impulse pressure fuze mine remains the predominant fuze type. [Ref. 8]

The track width mine plow (TRMP) weighs 3.5 tons and consists of two plow blades. The plow removes surface laid or buried mines from the path of the vehicle's tracks, the tines penetrate the ground to dislodge buried mines and bring them to the surface where they are cast aside. A dog bone and chain assembly is used to clear tilt rod mines in the same manner as the TWMR. [Ref. 9] It possesses the potential to provide effective mine clearing of surface laid mines and under certain terrain conditions, mines laid below the surface [Ref. 8].

Sweeping operations to clear a path through a minefield is carried out by the roller and plow sections simultaneously or by the roller section alone. When moving through a mined area, travel should be in as straight a line as possible and no sharp turns should be executed, otherwise a mine unearthed by the plow may pass under the tank's tracks. When choosing a movement route, it is desirable that this path lie along the smoothest possible course through the minefield. [Ref. 10] The best overall results are normally achieved when the two systems are used in tandem, with the roller leading until it detects (detonates) a mine. The plow then digs in and leads through the minefield, followed by the roller which proofs the lane. Once the minefield is passed, if further mines are anticipated, the roller resumes the lead. [Ref. 11] The company/team sized element conducting the hasty breach through a threat minefield and continuing on to seize the objective can effectively exert command and control of only one breach. [Ref. 4]

D. MEASURES OF EFFECTIVENESS

The measures of effectiveness concentrate on the principal purposes of countermine equipment which are to decrease the amount of time the unit is exposed in the attack, reduce delay time due to minefields, and to change the force ratio for the attackers. The MOEs are quantitative indicators of the equipment's ability to affect the battle outcome compared to various base case situations, (i.e. when the battlefield is void of obstacles and the battle outcome when the battlefield has minefields and the attacking unit does not possess any breaching/clearing equipment).

An integral factor in the determination of the number of breaching systems is the vulnerability of a specific device to direct or indirect fires, since the loss of a device (due to damage or failure) before or during the breach would require the employment of additional devices. Because of their relatively high degree of accuracy and standard coordinated employment with a minefield, direct fires are generally considered to be the predominant threat.

The final factor that must be considered in the MOE development is the expected reliability and survivability of the clearing or neutralizing device. This reliability denotes the probability of the device actually clearing or neutralizing a mine it encounters and the survivability of the device is the ability to withstand the rigors of mine detonations which may be encountered when clearing the obstacle.

The primary question of how the number of pieces of breaching equipment affects the battle is best answered by measuring the number of casualties suffered by the attacking force. If the equipment accomplishes its mission, such as allowing a rapid breaching of obstacles, there should be a decrease in the number of casualties due to both mine detonations and direct fire kills, or the minimum range between opposing forces should have decreased.

The MOEs are as follows:

1. percent of blue casualties due to direct fire.
2. percent of blue casualties due to mine detonations
3. percent of blue casualties due to both mine detonations and direct fire.
4. number of blue casualties due to mines/number of pieces of breaching equipment available.
5. number of blue casualties due to direct fire/number of pieces of breaching equipment available.
6. number of total blue casualties/number of pieces of breaching equipment available.
7. Number units going to defensive posture over 50 repetitions of the model.
8. Time of units going to defensive posture (number in the initial, early, middle and late portions of the battle).
9. Average length of battle.
10. Minimum range of blue forces

11. Rate of battle losses = number of casualties/minute of battle.

III. MODEL DEVELOPMENT

The model developed for this thesis is a time sequenced, stochastic, battalion level, force-on-force simulation. The model conducts the battle in uniform time steps of 30 seconds each. Figure 2 provides the general scheme for the sequence and flow of events in the model. The pertinent elements for the landmine simulation and analysis problem are the mine countermeasures equipment and the maneuver units. Other necessary values are the mine countermeasures equipment at the assault site and the characteristics of the equipment.

The simulation has been written to allow for maximum user flexibility while maintaining a simple and transparent structure. Unit formations can be easily changed, numbers and types of equipment are easily modified, and even the maneuver network can be easily changed. The full flexibility of the model is discussed in detail as each module is explored. Although the program code is listed in its entirety in Appendix B, the critical portions are discussed in the following sections.

The sequence of events for each time interval (30 seconds) contains six main phases: unit status, unit location, movement, Red detect/fire, Blue detect/fire and battle termination/results. The movement phase applies to the blue forces only. Generally, every blue unit is advanced the total distance it is able to travel based on

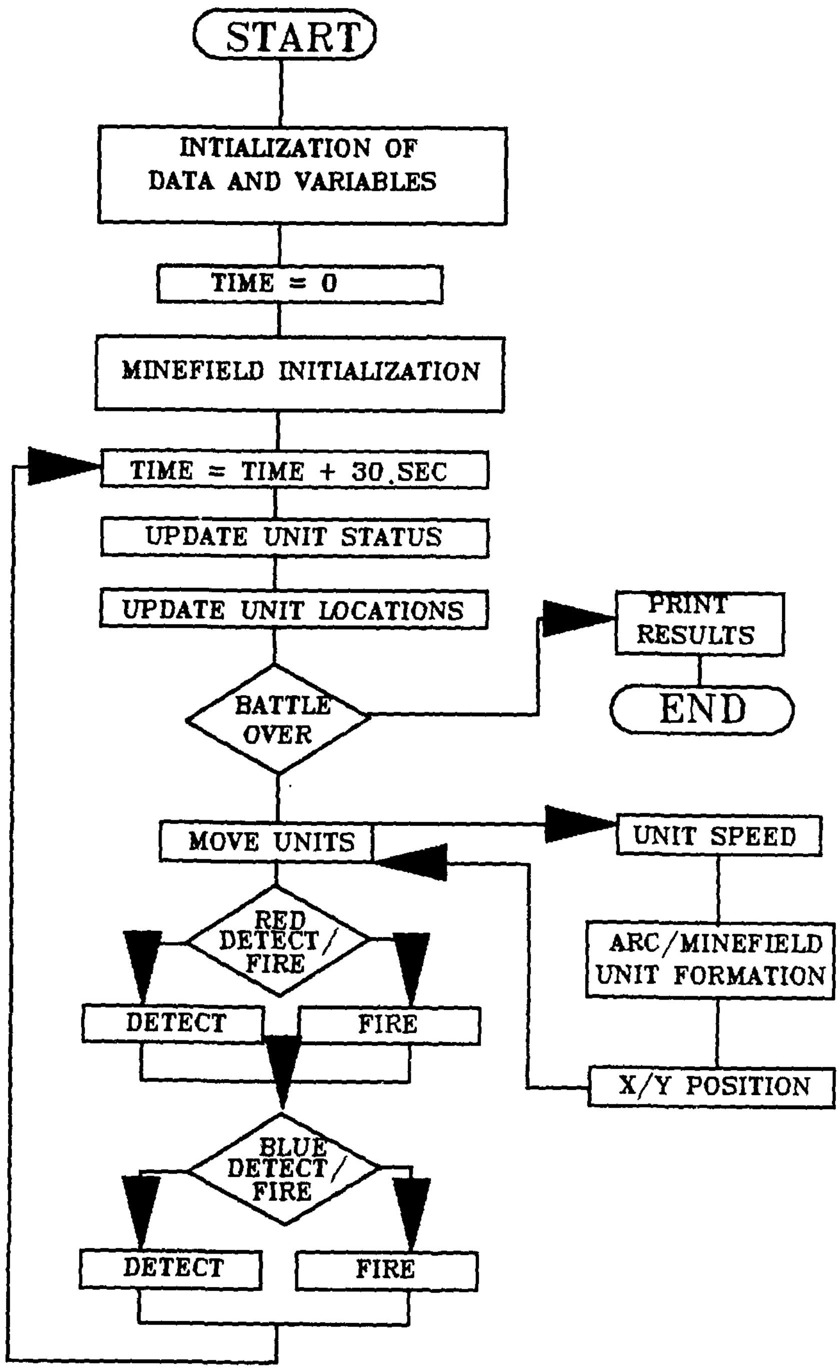


Figure 2. Model Flowchart

unit formation, types of equipment, terrain and location. The detection for both the red and blue forces is similar in that the time to detect is fixed at a given interval of thirty seconds. If it takes longer than 30 seconds to detect an opposing element, then that element is not detected. This concept is explored in more detail later in the chapter. The detection modules also serve to allocate the unit's fire, assigning targets to those elements who have detected them. The fire module is stochastically based, using probabilities of hit and kill given hit in a Monte Carlo model to determine the outcome of an engagement. If a hit on a target does occur, the model determines either a kill or no/unimportant damage to the vehicle. Once a vehicle has been killed it is removed from the simulation, no longer able to either provide additional maneuver or fire, nor can it be detected by the opposing forces.

Within the movement phase is the minefield logic. The module deals with a minefield in two phases, that of actions taken upon entry into a minefield and casualties due to entry, and actions taken during the breaching or bypassing of the minefield. The determination of whether a mine detonation occurs, the exact location of the detonation and the damage incurred is a function of the density of mines in the field, the effective vehicle width and the actual distance traveled in the minefield. Knowledge about the specific location of a minefield is gained in one of two ways, either by visual detection of the minefield prior to entry or by detonation of a mine after entry. Options based on minefield knowledge are discussed in a subsequent section. The mines are considered to be either surface laid or buried. Two minefields are modelled in the simulation, one emplaced far (approximately 3000 meters) from the objective and one emplaced near (approximately 1500 meters) the objective. The probability of detection for the far minefield is low due to the assumption of no reinforcing obstacles or readily identifiable boundaries. The near minefield's detection probability is set higher due to the likelihood of reinforcing the field with wire obstacles. The detection probabilities are, however, input data and may be changed to conduct additional analysis. Battle termination stops the simulation when either of the following criteria is met:

1. Red force strength falls below 25 percent
2. The minimum range between forces is less than 250 meters.

There are no battle termination criteria used for the blue force other than if a company's strength falls below 50 percent, it assumes a defensive posture.

In addition to the main simulation discussed above, an enhanced simulation was developed based on the concept of limited command, control, and communications (C^3) versus total C^3. The only control in the initial model is to insure an alignment of forces with respect to the range to the enemy.

In the enhanced model, in addition to the alignment of forces, the presence of minefields in the area of operations is communicated to the rest of the battalion after initial detonation or detection of the first minefield by the lead unit. This concept is discussed in detail in the minefield logic section of this chapter and is the only modification to the initial model. All other subroutines function the same in both models.

A. TACTICAL SCENARIO

The scenario used in the model is based in West Germany on terrain similar to that found near the Fulda Gap. The NATO forces have assumed an offensive posture and the 3rd Battalion, 35th Armor is to conduct a deliberate attack to secure near side crossing sites on the Ulster River on the East-West German border. Although enemy forces in the area have been weakened by the past days of fighting, front line troops are in prepared defensive positions protecting the crossing sites. The enemy is believed to be in an economy of force posture and has used reinforcing obstacles to strengthen its position. Reconnaissance by the Scout Platoon has been unable to provide enough information about possible minefields or gaps in the defending system, therefore the decision has been made to breach into and through the defending system in all cases except when breaching assets are not available. The enemy force is believed to consist of a tank company of T-72s reinforced by a platoon of BMPs occupying prepared defensive positions (Figure 3).

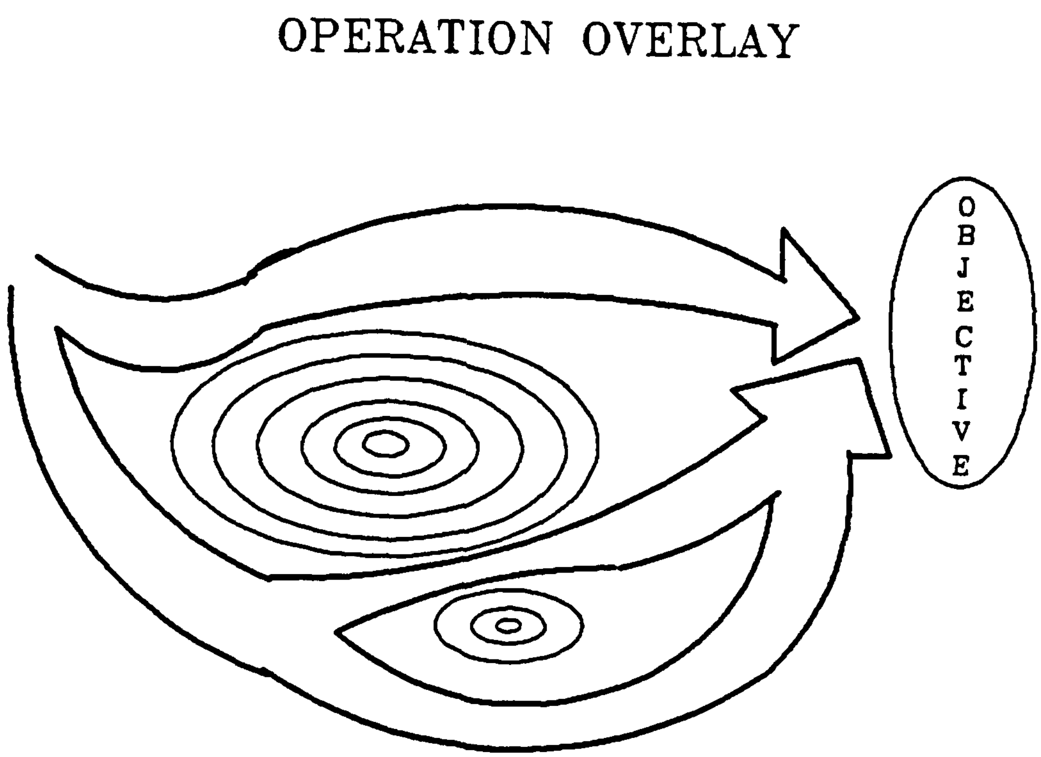


Figure 3. Operation Overlay

A quick attack is to be made by 3-35 Armor along twin axis of advance with selected limited objectives (Figure 3). The battalion will attack with two companies abreast on each of the two axis to secure the high ground on the objective currently held by the red forces.

B. INITIALIZATION AND DATA INPUT

There are fourteen data files which provide support to the simulation. These files support the movement network, the detection/fire modules, and the unit formation and breaching routines and are listed in Appendix C.

Data files 1 through 4 support the movement network by providing arc and node designators, locations of nodes, distances and headings of the arcs, speeds that the unit can maintained based upon terrain, equipment and formation, and the axis of advance for each of the four maneuver units.

Data files 8 through 11 delineate the four possible formations the blue forces are able to use in the conduct of the attack. Figure 4 shows the four formations. Formation configuration and vehicle placement are changed simply by changing the x and y offset positions from the control or ghost vehicle. The purpose of the control vehicle is described in the movement module.

In both versions of the model, formation 0 is used when a unit assumes a defensive posture; formation 2 is the formation used during the breach or bypass of an obstacle. Formation 1 is the movement/assault formation used by the unit at all other times in model 1. In the enhanced model formation 1 is used by all units until the first minefield is detected/detonated. Formation 3 is then assumed as the standard movement/assault formation at all times except when the use of formation 0 or 2 is invoked.

There are five vehicle type codes used in the simulation. Vehtype1 is the designator for a basic M1. Vehtype2 is for a mineplow tank with the plow in the raised position. Vehtype4 is the designator for the same type of vehicle, with the plow in the lowered or deployed position. Vehtype3 and Vehtype5 are used in the same fashion for the mineroller tank, 3 being used to designate the roller in the raised position and 5 to designate the roller in the deployed position. Both the mineroller tank and the mineplow tank can become a regular M1 tank if the breaching attachment is destroyed during conduct of the battle. Therefore it is possible to begin the battle with 10 tanks, 2 mineplow tanks and 2 mineroller tanks and end the battle with 14 regular tanks, if all the attachments were destroyed during breaching operations.

Data file 14 places the blue elements in specific positions outlined in the various formations (Figure 4). For example, if a unit consisted of 14 vehicles (10 tanks, 1 mineroller tank and 3 mineplow tanks) the entry order of

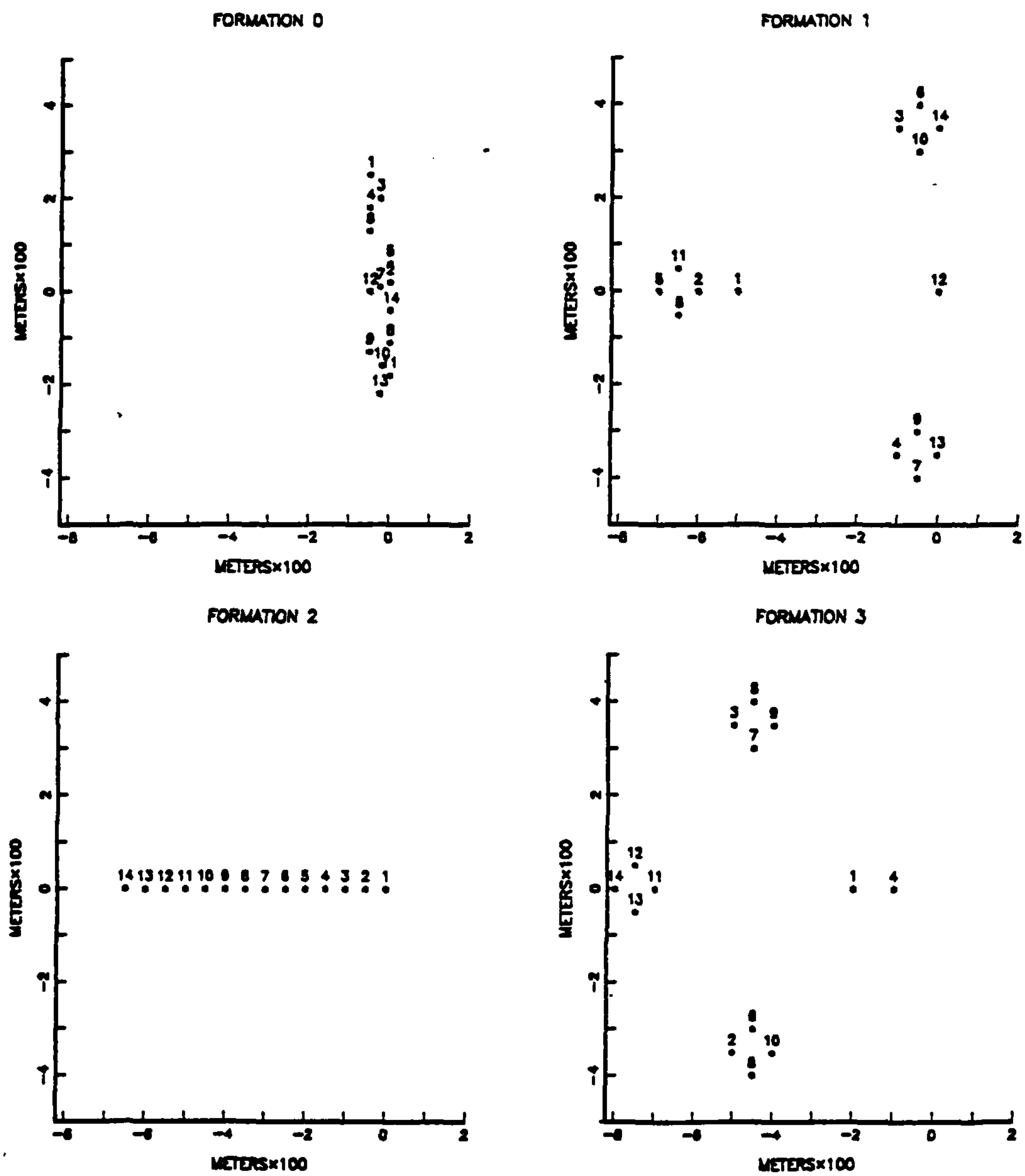


Figure 4. Unit Formations

the vehtype code into data file 14 is the position they would occupy in each of the formations. Therefore if the mineroller tank is entered first as vehicle type 3 in the file, it would occupy the number 1 position in each of the various formations, a mineplow tank entered second as vehicle type 2 in the file would occupy the number 2 position in all formations, etc. This obviously allows the configuration, in terms of numbers and types of equipment, of each unit independently as well as allowing each unit to place that equipment wherever it wishes within each of the formations. The only restriction regarding unit size is that they all must have the same number of total vehicles and that number cannot exceed 20 vehicles without changing the dimensions in the program. For example, one unit could have all tanks while another could have 10 tanks, 3 mineroller tanks and 1 mineplow tank.

The only vehicle type codes that are entered by the user are one, two, or three. The program will automatically change vehicle type 2 and 3 to 4 and 5 appropriately during breaching operations, changing them back to vehicle type 2 and 3 once the breaching operation in that particular unit has been completed.

Data files 12, 13, 15 and 16 support the red forces in such areas as position (file 12), the probability of looking in a particular direction (file 13), the vehicle type, height, and maximum engagement ranges (file 15) and finally the probabilities of hitting a target and killing the target given a hit, which obviously support the detection and fire modules. Data file 17 provides the probabilities of hit and kill for the blue forces in the same manner as file 16 for the red forces.

In addition to the data files, there are several initial data statements in the program which support the minefield setup module with minefield depths, densities, and probabilities of occurrence, all of which may easily be changed by the user.

C. MINEFIELD SETUP MODULE

The anti-vehicular minefield is represented in the simulation as a uniform distribution of mines which are randomly dispersed within the minefield. The minefields are modeled as continuous with the depths ranging from 150 to 300 meters for the minefields located at approximately 3000 meters from the enemy position and 200 to 300 meters for the minefields located approximately 1500 meters in front of the red force position. The minefield densities are expressed in terms of mines per square meter rather than the standard mines per meter of frontage.

Because the fields in this simulation have only a depth associated with them, this unit of measure for density is preferred. The density of the far field is .003 mines per square meter and the density of the near field is .02 mines per square meter. The densities and depths of the minefields can be easily changed by changing the data statements at the beginning of the simulation. By setting the maximum and minimum depths of the minefields equal, all fields will be of the same depth. The depth of each minefield is determined by a uniform (0,1) random draw which then determines the field dimension by

Depth of Minefield

=mindepth + ((maxdepth-mindepth)*U(0,1)) / 1000

(equation 3.1)

The basic concept of the minefield effects calculation is that of the expected distance to a mine encounter. Since the mines are randomly placed, the expected distance to the initial encounter and then each succeeding encounter is exponentially distributed. Therefore the expected distance to a mine encounter given by equation 3.2.

E[distance to encounter]=ln(1-U(0,1))/(-width*density)

(equation 3.2)

where the width is the effective width of the vehicle encountering the mine and the density is the density of the minefield in which the encounter is taking place. Successive distances to each encounter are thus calculated prior to the commencement of the simulation and are stored for future use.

One other feature which is included in the Minefield Setup module is the probability that a particular minefield is actually emplaced. In the simulation, runs were evaluated under a worse case scenario and a most likely or average case scenario. The most likely or average case scenario used a 70 percent chance of each of the far minefields being in place and a 90 percent chance of each of the near minefields being in place. Therefore the possibly exists on any single run for anywhere from zero to eight minefields to be in place facing the blue force, and on any single avenue from zero to two minefields to be in place, based on the random number draws. By emplacing the minefields in this fashion and then running multiple repetitions of the simulation, a long run average minefield emplacement will be achieved providing a greater degree of variability in the evaluation of the likelihood of success of a particular unit configuration.

D. UNIT STATUS MODULE

The unit status module serves to keep a running total on the losses of equipment by unit and type. It is in this routine that the determination of whether a unit goes to a defensive posture is made. If the unit is less than 50 percent effective (i.e., it has lost over half of its equipment), then it assumes a defensive posture, thereby decreasing the likelihood of acquisition by moving to a hull down position. This aspect will be discussed in more detail in the Red Detect module. When a unit goes to a stationary defensive posture, there is no impact on the speeds of the remaining units.

E. UNIT LOCATION MODULE

The unit location module exerts command and control over the battalion by delaying units which are moving too fast. The ranges to the enemy force of all four blue units will be in the interval [rngmin,rngmax] where the two limits are determined by the unit closest to the enemy force (rngmin) and the unit farthest from the enemy force (rngmax).

The module computes the range to the objective of each unit. If the range difference between all the units is less than 500 meters, then all units proceed at the maximum speed possible as determined by terrain and equipment in each unit. However, if the range difference between the closest and farthest units is greater than 500 meters, then the speed of the closest unit is adjusted downward by a lag factor, AAA. The factor AAA is computed by equation 3.3:

$$AAA=(rngmax-rngmin)/lag \qquad \text{(equation 3.3)}$$

where lag is the maximum distance allowed between the closest and farthest units: in this case, 500 meters. This value is then passed to the movement module where it is used to decrease the speed of the leading unit. As an example, if the range of the closest unit is 2.4 kilometers and that of the farthest unit is 3.2 kilometers, then the value of AAA would be:

$$AAA = (3.2-2.4)/.5 = 1.6$$

This value is then used to decrease the speed of the leading unit by a factor of 1.6. Thus for a speed of 25 kilometers per hour decreased by an AAA of 1.6, the new speed of the unit would be 15.625 kilometers per hour.

F. MOVEMENT MODULE

The movement logic is first discussed in detail without the minefield modules included. Minefield tactics and how they impact on the movement routine are discussed in the following section. The Movement module is made up of three distinct routines; a determination of unit speed, location and distance traveled along an arc, and the location of each of the elements in the unit in x and y coordinates (Figure 5).

Unit movement consists of moving each unit along a network of arcs, each of which has a distance, heading and speed associated with it. The network used to support this simulation is shown in Figure 6. A unit starts at the tail node of the arc, moving as far as possible in the 30 second time interval, based on the allowable speed associated with that particular arc and the type of equipment in the unit. For each 30 second time step the following process is followed for each unit in the Movement module. On entry into the subroutine the first decision is whether or not

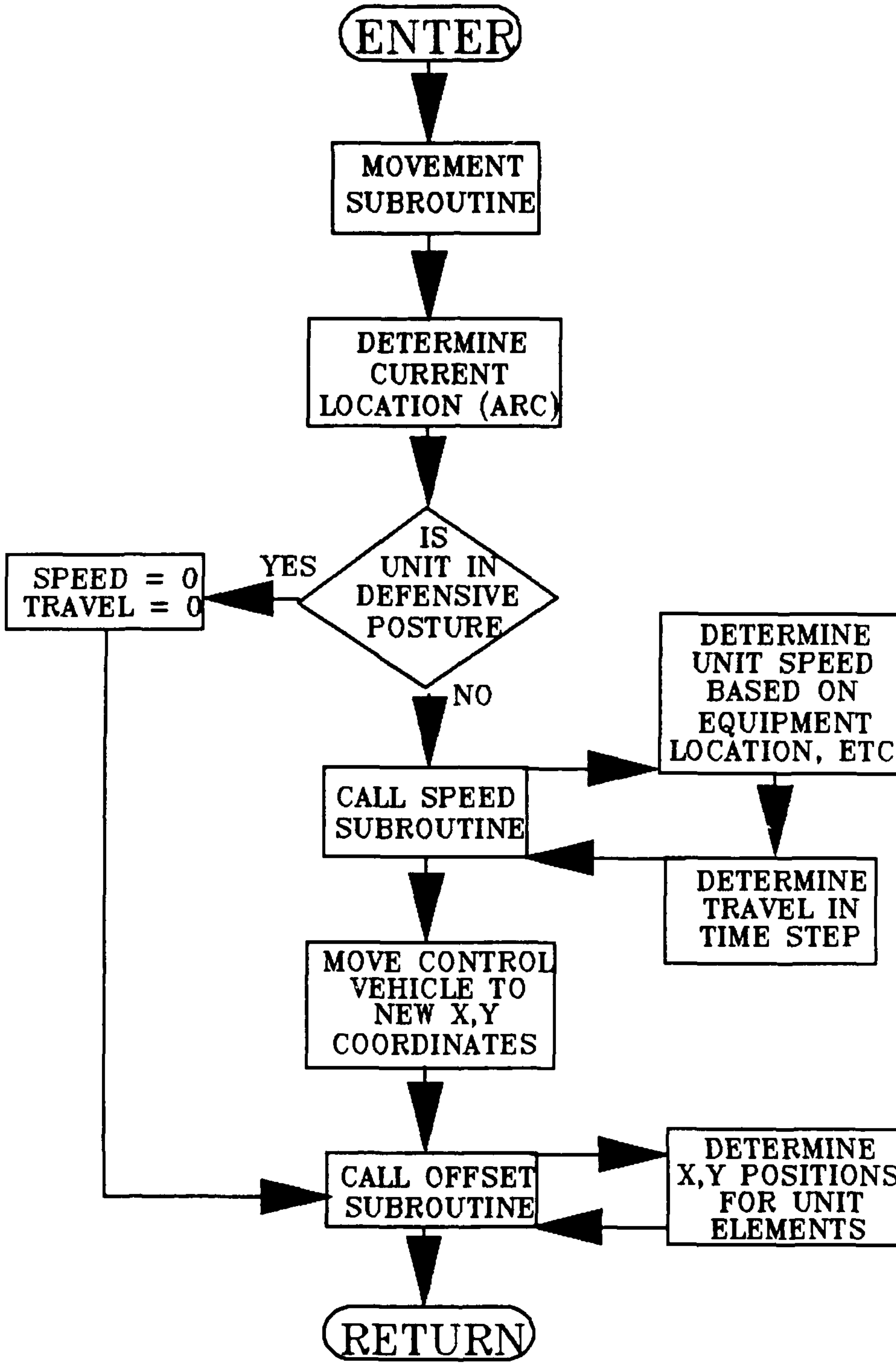


Figure 5. Movement Flowchart

the unit is in a defensive posture. If it is, then the unit speed is set to zero and the logic loops to the offset routine where the x,y position of each element is determined.

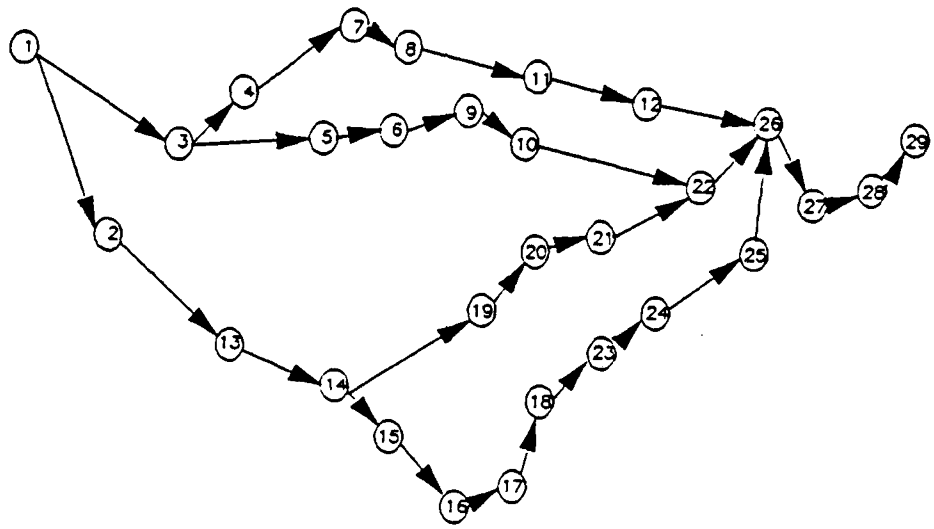


Figure 6. Network Supporting Movement Routine

If the unit is still combat effective the Speed subroutine is entered to determine the unit's speed and travel. The first step is to determine the maximum speed a unit can maintain on a given arc based on equipment in the unit and terrain characteristics for that arc. The trafficability and slope of the terrain are taken into account by degradation of the unit speed as shown in the Speed file (Appendix C).

If the unit has a mineroller tank, then that vehicle is the limiting speed factor unless the unit also has mineplow tank which is currently being employed, in which case that vehicle is the limiting speed factor. The speed of a unit may vary on a single arc as the unit's equipment changes configuration or is attritted. Once the speed of the unit is determined, if it is the unit closest to the enemy and the lag factor, AAA, is greater than 1, then the speed is decreased accordingly. Once the final speed for the time step is determined, the travel for the thirty second interval is determined and control returns to the Movement module.

The ghost vehicle is the only vehicle that is actually moved and controlled by the model. Once the speed and travel of the unit is determined, the ghost vehicle is moved to a new set of x,y coordinates along the arc. Then, depending on the current formation of the unit, the elements are positioned by the Offset subroutine. The new positions are determined by the x and y offset distances obtained from the appropriate formation data file and are adjusted depending on the current heading of the ghost vehicle along the arc (Figure 7).

As an example, an element that is offset (-1.0,1.0) is 100 meters up and 100 meters behind the ghost vehicle. If the current position of the ghost vehicle is (483,621) and it's heading is due east then the element is located at (482,622). If, however, the ghost vehicle was at the same location but heading northeast (45 degrees from the x axis), then the location of the element is (483.0,619.6).

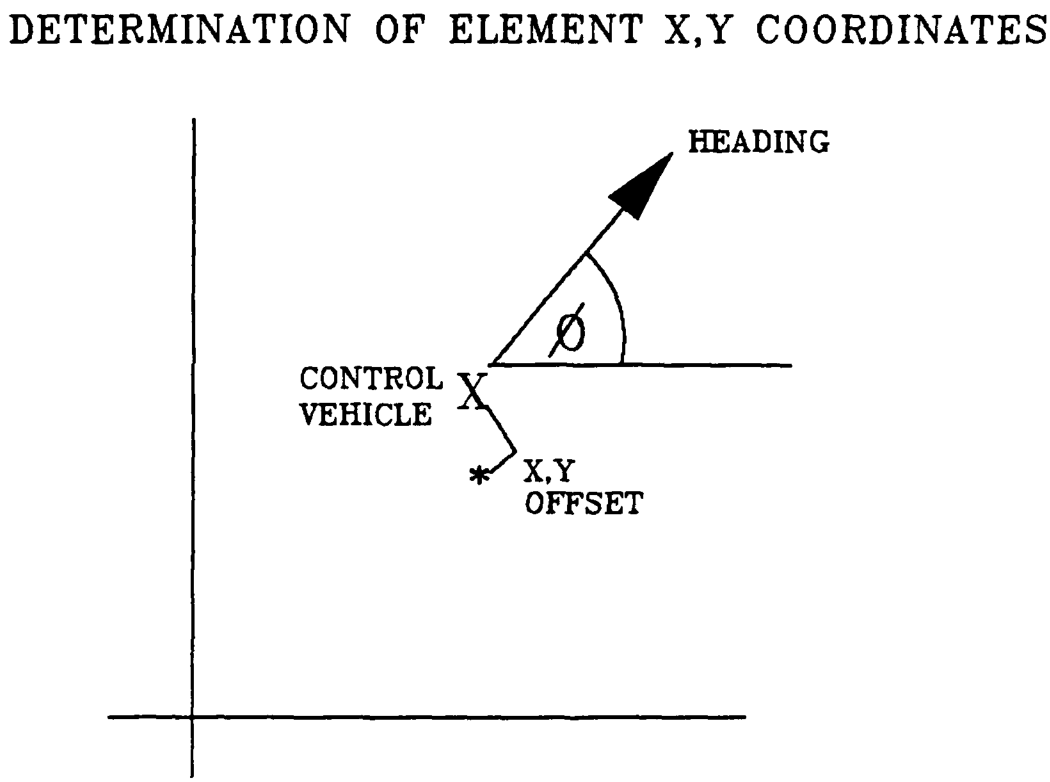


Figure 7. Determination of Element X,Y Coordinates

When the unit reaches the end of an arc, the unit assumes the new heading and speed associated with the next arc in the network. In this fashion, all units are able to move independently over any network which may be developed to support the scheme of maneuver.

G. MINEFIELD LOGIC

Once the Movement routine was developed, it was a simple matter to construct and insert the minefield logic which is the heart of the simulation. The minefield logic, like the rest of the simulation, is flexible in nature, allowing for an unlimited number of configurations. Minefields may be placed on any arc in the network, the only restrictions being that the arc must be longer than the depth of the minefield and only two minefields per avenue of approach may be input. The probability of a minefield being in place, the density of the minefield and the maximum and minimum depths are all input by the user.

The minefield logic is discussed in two phases: first the actions taken on entry into the minefield, and second, the actions occurring during the breach of the minefield.

H. INITIAL ENTRY INTO A MINEFIELD

A decision model has been developed which represents the process by which a unit commander selects one of the three possible options available to him when a vehicle in his unit detonates a mine or the location of the minefield is detected visually. Figure 8 shows the general sequence of events involved in the minefield detection logic. As discussed earlier, he may choose to:

1. conduct a hasty breach if the unit possesses any breaching equipment;

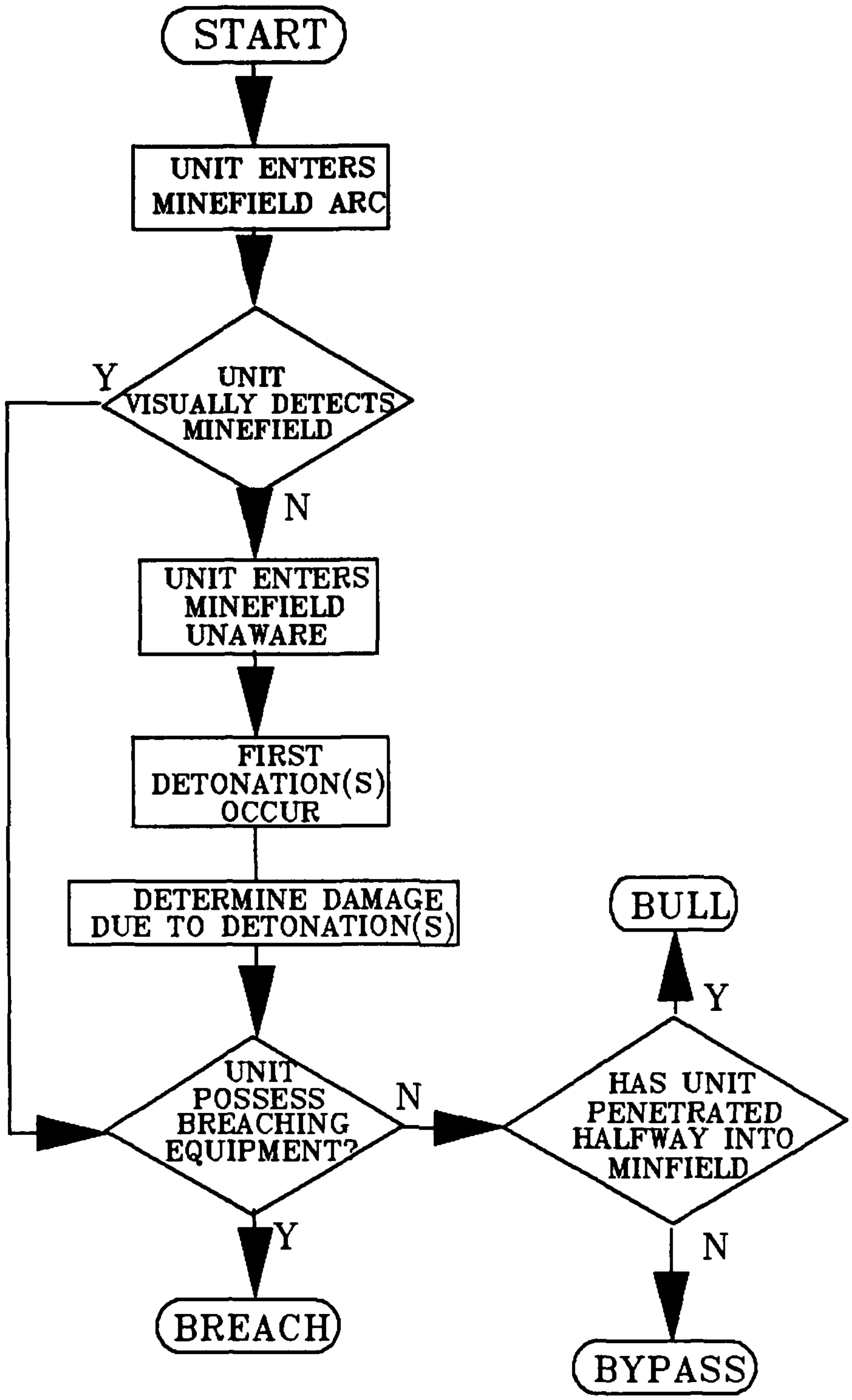


Figure 8. Minefield Logic Flowchart

2. bypass the minefield if the tactical situation permits or he does not possess any breaching equipment; or

3. order a "bull through", hoping to clear a lane without sustaining overwhelming casualties.

The choice the commander makes in the simulation is based on the knowledge he currently possesses about the minefield. Once that knowledge about a particular minefield is gained, it is assumed to be perfect knowledge in regards to the boundaries of the minefield and the unit's location within that minefield. If the knowledge about the minefield is gained prior to entering the minefield, then the model will elect one of two options; either a breaching operation if the unit currently possesses breaching equipment, or a bypass if it does not. The breaching operation begins at the edge of the field and distances to mine encounters are retrieved from the array previously calculated in the minefield setup module.

If the knowledge about a minefield is gained after entry, it is gained the hard way by detonation of a mine. The simulation is able to react in one of three ways. If the unit possesses any breaching equipment, it begins a breaching operation from the point where the mine detonation took place, since it is assumed that up to that point the minefield has been successfully breached. If the unit does not possess any breaching equipment, the decision to "bull through" or bypass is based on the distance into the minefield that the detonation took place, thereby assuming perfect knowledge for the commander on the specific boundaries of the minefield once it is identified. If the detonation occurred less than half way through the minefield, the unit commander elects to conduct a bypass operation. If the unit has penetrated more than half way through the minefield prior to the first detonation, then the unit will "bull through" the minefield, hoping to minimize losses as compared with attempting to back out and bypass the obstacle.

In all cases, regardless of the option chosen by the unit, the following two actions occur. The unit is assessed a thirty second delay in movement while changing formations and any enemy elements which have been detected by the unit entering the minefield are lost. Therefore, if in the period (t,t+30) the unit had detected an enemy element, during the normal sequence of events that element would have been engaged during the period (t+30,t+60). However, due to the minefield encounter occurring during the period (t+30,t+60), all detections are lost and all elements in the unit entering the minefield must reenter the detection module during the period (t+30,t+60). Additionally, at any time the unit is in a breaching operation all vehicle types 2 and 3, which are now coded as 4 and 5, respectively, cannot conduct direct fire engagements. This restriction occurs because the crew is occupied with the conduct of the breach as opposed to trying to detect the enemy.

I. BREACHING OPERATIONS

If a minefield has been entered, the breaching operation commences. Although the bypass is not really a breach of the obstacle, it does allow the unit to circumvent the minefield and continue its mission.

In the simulation the bypass option is dealt with rather simply. Rather than building additional arcs and nodes as a bypass route, which would invariably restrict the placement of minefields, the unit's speed is simply degraded and the mine detonation routine is suppressed. In this manner the unit is subjected to enemy fires for a longer period of time and the delay in forward progress accurately simulates the requirement to move parallel to the minefield in hopes of discovering a route around the obstacle.

A similar methodology is used for the "bulling thru" technique. The unit, in it's attempt to "bull thru", maintains a single column formation, thereby reducing the exposure of trailing elements to mine detonations.

The formation the unit uses while breaching the minefield is specified as input to the model. In this simulation, the formation used in all breaching operations is a single column of vehicles with all the breaching assets at the head of the column.

The unit will conduct the breach if it possesses the requisite assets. The simulation places all the breaching equipment at the front of the formation, with all the mineplows leading, followed by the minerollers, then followed by the remaining vehicles in the unit. The order that the vehicles enter and breach the obstacle is user input through the use of formation 2. The simulation does allow for a breaching device to be destroyed without destroying the carrier on which it is mounted. If a breaching device does become inoperable, then that vehicle's type code is changed to a 1 (M1 tank) and it is cycled to the rear of the formation. In this fashion, a vehicle with no breaching device does not lead the breach (unless there are no more breaching assets in the unit).

The simulation will allow any of the following cases to occur depending on the random draw.

1. A clearing device may be destroyed.
2. The carrier of a breaching device may be destroyed.
3. A mine may be left uncleared.

In case 3 a following vehicle may clear the mine if it has a breaching device, or it may detonate the mine and be killed.

In the breaching logic, mine encounters by each type of vehicle are dealt with in the following manner. If a vehicle type 1 encounters a mine, a random draw is conducted to determine a kill or no/unimportant damage.

For the M1, all mines are detonated when encountered and none are left uncleared under the tracks.

If the lead vehicle is a mineroller, there is a two step process in the determination of the probability of clearing and surviving the mine encounter. Figure 9 shows the process for the clearing of mines by the mineroller tank. When a mine is encountered there exists a probability associated with the clearing of the mine and, then given the clearing (by detonation with the rollers), a probability associated with surviving the blast.

Although the operation is similar for the mineplow, a mine encounter involves a three step process to determine the outcome of an encounter. Figure 10 shows the methodology used for an encounter by a mineplow tank. There is

1. a probability associated with clearing the mine,
2. a probability of detonation given the plow cleared the mine and finally
3. a probability of surviving, given the detonation by a cleared mine.

If a unit has breaching assets, then it conducts a breach. However, after losing its last piece of breaching equipment the decision to "bull thru" or bypass is the same as when the field is first encountered. If the unit has not penetrated at least halfway through the minefield, then it conducts a bypass. If it has reached the halfway mark,

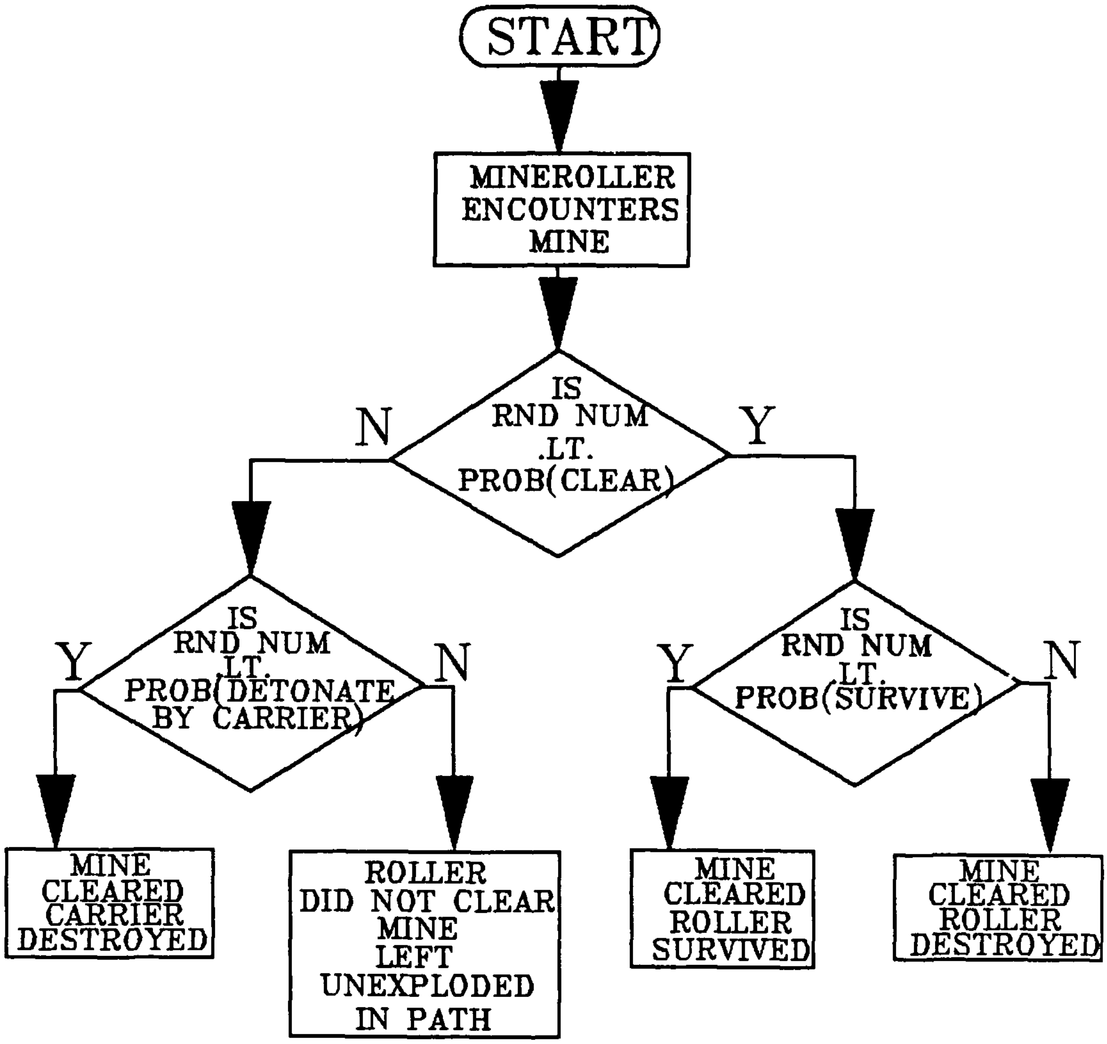


Figure 9. Mineroller Breaching Flowchart

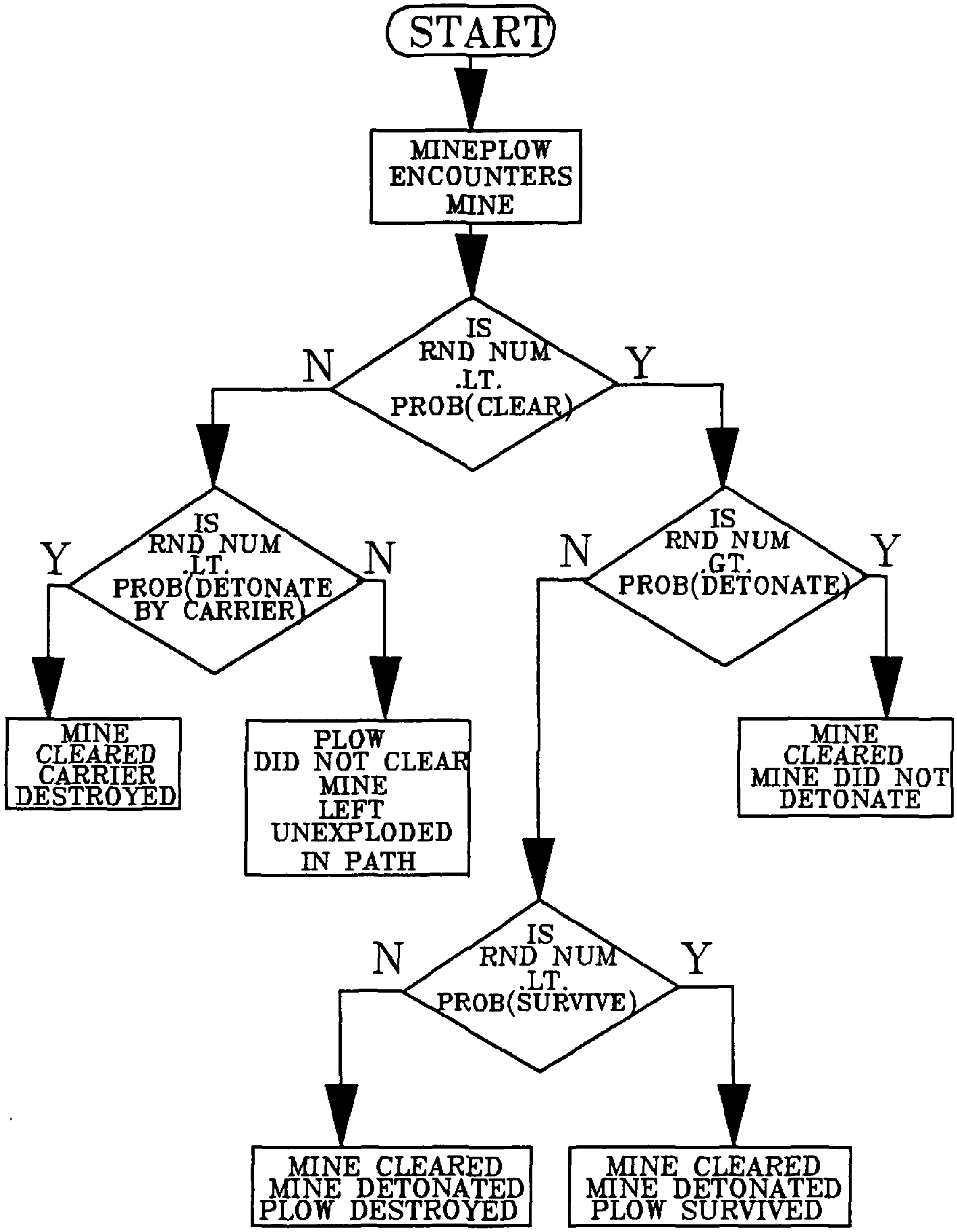


Figure 10. Mineplow Breaching Flowchart

then the unit will "bull" the rest of the way through the minefield.

In Model 1, units encounter and deal with each minefield entirely on their own. There is no communication between units regarding the encounter of a minefield. Each unit stays in formation 1 until they either detect or detonate a minefield, suffering the losses associated with each encounter. Once the field is cleared the unit returns to formation 1, and the process is repeated for the second minefield.

With Model 2, communication regarding minefield locations is simulated. When the lead unit encounters the first minefield, all the other units in the battalion assume a detection formation. Formation 3 in Figure 4 is used for this purpose. The mineroller tank is placed in the lead in hopes of detecting the location of the minefield on the axis of advance by the rollers and avoiding vehicle losses due to detonations. Additionally, when the unit exits the minefield, it resumes formation 3, as opposed to Model 1 where the unit assumes formation 1.

Once a unit has successfully breached a minefield, vehicles in that unit are not subject to mine detonation since the clearing operation is assume to be completely effective. Prior to that point, mines that were not cleared by a breaching vehicle may detonate and cause casualties to following elements.

J. FIRE AND DETECTION MODULES

The Fire and Detection modules operate simultaneously in the model. It is possible for different elements of the same unit to be detecting or firing during the same 30 second time period. The model does not restrict the unit to either the detection or firing phase during each time step. All elements initially start out in the detection mode. When element i detects an opposing element j during the period (t,t+30) then during the following period (t+30,t+60) element i enters the firing module and conducts the engagement. If the detection of element j occurred during the period (t,t+30) then during the following 30 second time period line of sight is assumed to continue to exist for the firing phase. It is also assumed that if element i is busy firing during the period (t,t+30) then no target search is conducted by element i during this time interval.

The red forces may detect or engage , depending on the type of vehicle, up to two enemy elements in the thirty second time period due to their stationary defensive posture. Tanks can detect or engage two elements in the thirty second period while a BMP is able to either detect or engage only one target during the time interval due to the characteristics of the weapon system.

The blue forces, due to their offensive posture, are able to detect or engage only one enemy element in a time period. As a control for fire distribution only 2 red elements may detect or engage any single blue element at a time while 4 blue elements may detect/engage any single red element at a time.

Once a firer has completed his direct fire engagement(s), he returns to the Detect module during the next time period regardless of the outcome of the direct fire engagement. Even if during the period (t,t+30) element j engaged but did not kill element i, he must still go back to the Detection module during the next time step and attempt to redetect element i.

K. DETECTION MODULE

The Detection modules for the red and blue forces are exactly the same except for minor differences which will be pointed out in the discussion as they occur. Figure 11 shows the flow through the red Detection module. The only difference in the flow through the blue Detection module is that the red forces are always in a defensive posture, therefore there is no need for crossing velocity calculations.

The detection computations used in the simulation were adapted from the DYNTACS model with some minor changes. [Ref. 12] For each element i the computations look at every enemy entity in the thirty second period to determine if they can be detected. A detection rate, DETRATE, for

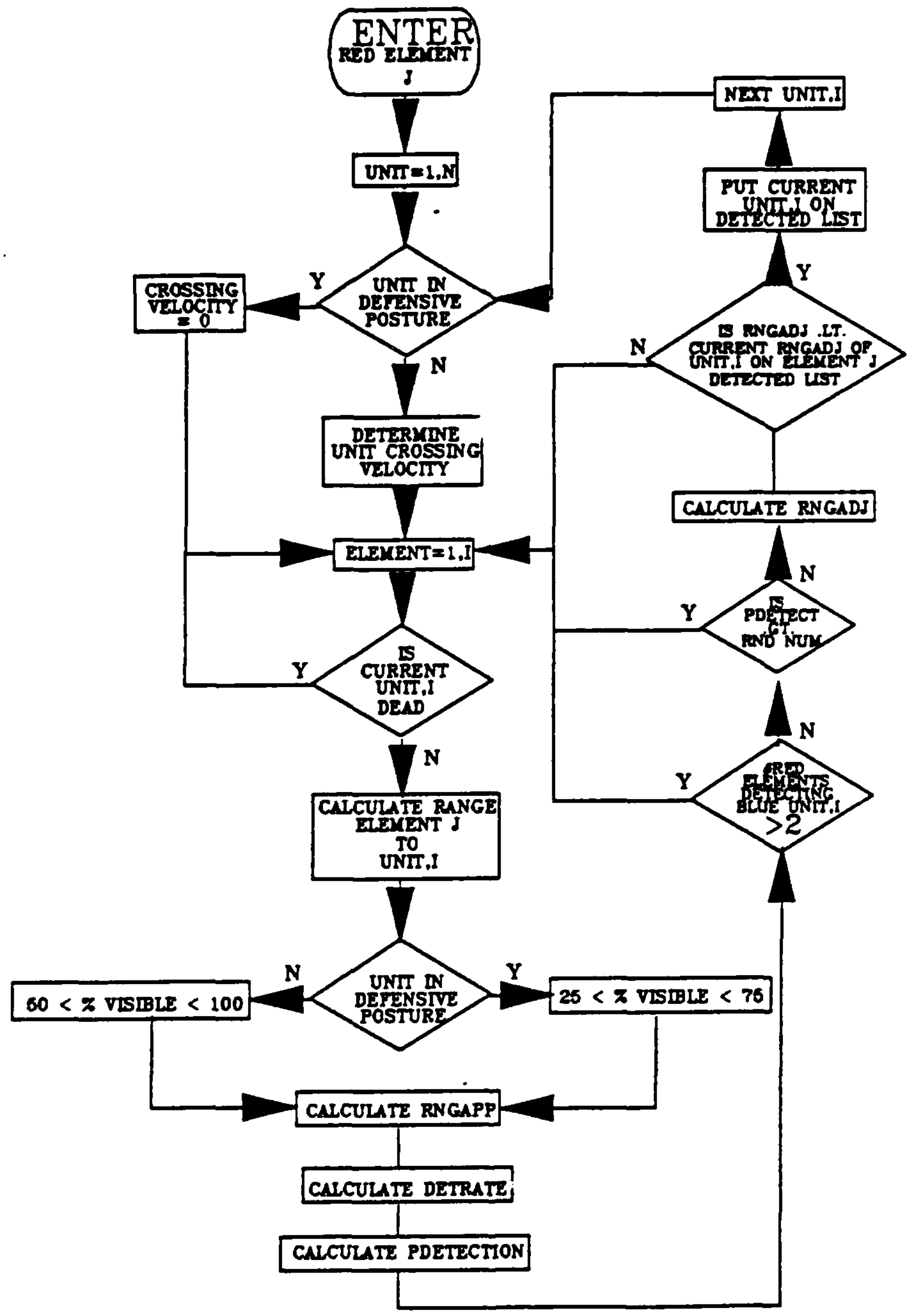


Figure 11. Red Detection Flowchart

every enemy element is computed is assumed to be constant for at least 30 seconds. Then the continuous looking model is used to compute the probability of detection in equation 3.4.

REDPDET = 1 - exp(-DETRATE * T)

(equation 3.4)

where T equals 30 seconds. Finally a Bernoulli trial is performed to determine whether or not the target is detected.

The detection rate equation 3.5 DETRATE is:

DETRATE = RPLOOK * (-0.003 + [1.088 / DENOM])

(equation 3.5)

where:

DENOM = 1.453 + (TAU * (0.05978 + 2.188 * RNGAPP * RNGAPP) - 0.0538 * CV)

and where the observation conditions are described by:

TAU = terrain complexity code; it can take on values from 1 to 7

RNGAPP = apparent range in kilometers. The apparent range is the range at which a fully exposed M60 tank would present an image which is the same height as the image that is observed for the current target. RNGAPP is computed as:

RNGAPP = (actual range * M60 height)/(target height * percent visible)

where the denominator in the simulation is a random variable. For the attacking blue force, the percent visible ranges from 50 to 100 percent for an offensive posture and from 50 to 75 percent for those unit which have assumed a defensive posture. For the red force the percent visible ranges from 25 to 50 percent due to the availability of prepared defensive positions.

The crossing velocity (CV) is measured in meters per second and is the target velocity component which is perpendicular to the target-observer line. It is the component of target movement which is most noticeable to an observer. The crossing velocity for the red force is zero, since they are in stationary defensive positions. When a blue force goes to a defensive posture, the model also sets their crossing velocity component to zero.

RPLOOK is the probability that the observer is looking in the direction of the target and is a user input in the model. For the blue force it is a constant 75 percent chance of looking in the direction of the target and for the red force it is dependent on the avenue of approach.

L. DIRECT FIRE MODULE

The Direct Fire module is stochastically based using probabilities in a Monte Carlo model to determine the outcome of an engagement. The range from the firer to the target is calculated and then used in a table look-up to determine the probability of a hit and of a kill given a hit. The values are then compared to a random draw to determine the outcome of the engagement. The only outcomes are either a kill or no/unimportant damage. If a target is killed it is assigned a "dead" code and is removed from the simulation.

This completes all the necessary modules required to conduct the battle simulation to generate the data necessary to analyze the measures of effectiveness developed in Chapter 2. The output is analyzed and the MOEs are evaluated in Chapter 4.

IV. OUTPUT ANALYSIS

A. BASIC RESULTS

The purpose of the simulation is to generate output to be used in the analysis of measures of effectiveness (MOEs). In this section numerical results are presented for each configuration and scenario. Fifty repetitions of each configuration were conducted and there were 5 different configurations evaluated against four different scenarios. The output provides a performance evaluation prediction of the mine countermeasures equipment. The four scenarios allow for the MOEs to be evaluated under varying conditions.

Scenario 1 evaluates the unit's performance when facing only direct fire weapons. The purpose of this scenario is to determine the impact of the countermine equipment on the unit's ability to fight when no obstacles are present. Scenarios 2 and 3 evaluate the unit's performance when faced by a combination of direct fire weapons and minefields. Scenario 2 examines the situation where there is a probability that the minefields are emplaced; Scenario 3 looks at the worse case situation: the probability of the minefields being in place is equal to 1. Scenario 4 is used to determine the effectiveness of the countermine equipment when faced only with minefields.

Sample data files used to support the evaluation of the MOEs are shown in Tables 1 and 2 (all tables and figures follow this chapter). In the heading of Table 1, the starting force configuration is shown. Columns 1 through 4 tabulate the direct fire losses by repetition. Column 1 is the total number of losses, column 2 is the direct fire losses of the M1, column 3 is the direct fire losses to the mineplow tanks and column 4 is the direct fire losses to the mineroller tanks.

Columns 5 and 6 of Table 1 give the losses of the breaching device due to mine detonations. Columns 7 through 10 represent the losses to the force due to mine detonations, each column representing the equipment in the same order as for the direct fire losses. Columns 9 and 10 represent the losses of the mineplow and mineroller tanks when they are not in a breach mode, i.e., the breaching device was not employed at the time of detonation.

Columns 11 and 12 represent the losses of the mineplow tank and mineroller tank due to mine detonations while attempting to breach the minefield. Column 13 is the total number of kills due to both direct fire and mine detonations and is the summation of columns 1,7,11 and 12. Column 14 is the length of the battle while column 15 is the minimum range attained by any unit during the battle.

Table 2 gives the status of the minefields on each axis and the time a unit went to a defensive posture. Columns

M1 (far minefield) and M2 (near minefield) give the status of the minefield, a 1 representing an active field while a 0 represents an inactive field. The time to defensive posture is given for each unit, a time of 0.0 meaning the unit did not assume the defense. The last column is the time to battle termination and is the same as column 14 in Table 1.

Tables 3,4,5 and 6 show the results of the evaluation of the output as derived from the MOEs. The sample mean is given, followed by the sample standard deviation in parentheses. Each column is the evaluation of a particular configuration against all applicable MOEs. Obviously in some cases an MOE does not apply due to a quantity required not being available, such as the number of pieces of breaching equipment in the unit configuration 14/0/0.

B. EVALUATION OF MOEs

MOEs 1 (Figure 12), 2 (Figure 13) and 3 (Figure 14) all deal with losses to the blue force versus their starting strength. The value for MOE 1 was found by using column 1, Table 1 divided by 56 to give a percentage of losses due to direct fire. Figure 12 shows the comparison of each configuration under each scenario. Direct fire losses for configuration 14/0/0 are low when no mines are present, but are the highest of any configuration as soon as minefields are introduced into the area of operations. Of interest is the fact that even though the configurations with breaching equipment have higher direct fire losses than the configuration without breaching equipment, the difference is 3 or 4 percentage points at most.

MOE 2 examines the losses due to mine detonations in Figure 13. Values are found by summing the losses in columns 7,11 and 12 from Table 1, and dividing by the starting strength of the battalion. Intuition would dictate that the losses to the force with no breaching equipment would be higher than those configurations with breaching equipment. This is not the case. Since each unit acts independently to detect minefields and the formation used does not place the breaching equipment in the lead, losses due to initial entry into a minefield should be the same for all force structures. It is at this point that the casualties due to mines increase for the forces with breaching equipment. The unit with no breaching equipment will usually bypass the minefields and therefore sustain no further mine casualties, while the units with breaching equipment conducts a breach, losing more equipment to mines in the process.

MOE 3 compares the losses to each unit due to both mines and direct fire in Figure 14. The values are found by using column 13 from Table 1 divided by 56. It is interesting to note that in the cases of the probability of minefields with direct fire and 100 percent probability of minefields with direct fire, the 12/1/1 configuration performed better than the 10/2/2 combination. This is due to the fact that most of the breaching assets in the 12/1/1 configuration are lost during the breach of the far minefield and the unit is able to travel faster in the 2600 to 1500 meter range band, thereby being subjected to the enemy's direct fire weapons for a shorter period. Of the configurations with breaching equipment, the 8/3/3 unit does the best when there is no direct fire.

MOEs 4,5 and 6 compare the losses of equipment versus the number of pieces of breaching equipment available in the unit. Their values are computed in the same manner as MOEs 1,2 and 3 except the denominator is the number of pieces of breaching equipment. Due to a changing denominator, the comparison of the of the various configurations is difficult. However the MOEs show the increasing number of casualties as the probability of the minefields increase (Figure 15). The synergistic effect of the combination of direct fire and minefields is clearly evident (Figure 16). The losses to any of the forces is the lowest when faced by direct fire only, increasing slightly when faced by minefields only, and increasing drastically when the combination of the two systems interact to defeat the enemy (Figure 17).

Since the number of pieces of breaching equipment are the same in the 10/2/2 and the 10/3/1 configurations they may be examined in more detail for these MOEs. The 10/2/2 configuration performed better when the unit was faced by direct fire only or minefields only, however the difference is minimal. When faced with a combination of mines and direct fire, the 10/3/1 configuration fared slightly better in both the number of direct fire casualties per piece of breaching equipment (Figure 16) and the total number of casualties due to mines and direct fire combined (Figure 17).

The number of units going to a defensive posture is shown by MOE 7 (Figure 18). The number is obtained from columns 3,6,9 and 12 from Table 2. In the scenario with direct fire only, the number of units going to defensive posture is relatively the same for all configurations, thereby again substantiating the point that the countermine equipment does not impact a great deal on the unit when it is faced only by direct fire. Even when the units are faced by scenario 2 (probability of minefields and direct fire) the number of units going to defensive posture does not differ a great deal. It is only when there exists a 100 percent chance of minefields that differences becomes large. The best performer for the configurations with breaching equipment when faced only by minefields is the 8/3/3 combination while the 12/1/1 combination was the worst. However when faced by the probability of minefields and direct fire the number of units going to a defensive posture was significantly lower for the 12/1/1 combination and even the 10/2/2 combination did better. This can be attributed in part to the fact that the breaching equipment is prevented, by the simulation, from engaging while breaching operations are taking place.

MOE 8 examines the period in the battle when the units went to a defensive posture (Figure 19). The battle was divided into four time periods - beginning, early, middle and late - each period representing one fourth of the duration of the battle. The determination of which period a unit went to a defensive posture was calculated by taking the battle time of each repetition and determining in which quarter the defensive times fell.

Once again all configurations performed equally well when there were no minefields and the units were faced only by direct fire. In this MOE all the configurations with breaching equipment performed better then the 14/0/0 configuration. The 14/0/0 configuration tended to go to a defensive posture much earlier in the battle due to the reduced speed imposed by the bypass routine. The 14/0/0 configuration is able to reach the far set of minefields quicker then the other configurations where it is then stopped and is attritted by the enemy. The configurations with breaching equipment were able to keep moving much longer in the battle, with the 10/2/2 combination performing the best.

The length of the battle is described by MOE 9 (Figure 20). Once again the numbers are misleading unless they are examined closely. In scenario 1, the 14/0/0 unit is able to close with the enemy much sooner (due to no speed degradation caused by the breaching equipment) than the units with breaching equipment. The length of the attack is approximately six kilometers and the higher speeds of the M1 unit allows it to travel faster. Similarly, the probability of minefields combined with direct fire still produced quicker battle times for the 14/0/0 combination, since if at least two units did not encounter the far minefield, they could close rapidly with the enemy and defeat him. The time of battle for 100% minefields and direct fire is essentially equal for all configurations, with the 14/0/0 configuration able to move rapidly between minefields and then losing time while bypassing. The average length of battle when there are only minefields present was approximately the same for all configurations with breaching equipment. It was also approximately the same when each configuration is compared between the two scenarios of 100% minefields/direct fire and when there are only minefields present. The big increase in time occurs in the 14/0/0 configuration, starting from a low in the 0%/direct fire scenario to a maximum in the 100%/no direct fire case. It should be noted that the only battle termination criteria that applies in the 100%/no direct fire is the minimum range requirement of 250 meters and this requirement causes the 14/0/0 configuration to bypass both the far and near minefields.

The average range at battle termination is MOE 10 (Figure 21). All values are approximately the same with one notable exception, that of the 14/0/0 configuration in the scenario of probability of minefields/ direct fire. This dramatic increase, in relation not only with itself but also with the other configurations, is attributed to the fact that the units on the avenues that are not faced by a minefield move rapidly through the area and suddenly find themselves in a direct fire battle with the enemy where they are attritted to a defensive posture early in the battle. This fact is substantiated by consideration of MOE 8, Figure 19, where the number of units going to a defensive posture in the middle of the battle is substantially higher for the 14/0/0 configuration.

The rate of battle losses is the last MOE. Figure 22 shows the rates which were determined by taking the total number of casualties per repetition (column 13, Table 1) and dividing by the length of battle for the repetition (column 14, Table 1). The figures, when comparing the 14/0/0 configuration with the rest of the configurations, are somewhat misleading. The 14/0/0 had the least number of losses in all cases, but since they are able to travel faster, battle time was shorter, causing the rate to appear artificially high. Among the configurations with breaching equipment, there is no single best performer, although the 12/1/1 and the 8/3/3 configurations were better than the others.

C. SUMMARY OF RESULTS - MODEL ONE

Upon examination of all the configurations with breaching equipment under the four different scenarios, the best performer was the 12/1/1 combination. The reason is that the breaching assets of the 12/1/1 configuration are, in most cases, just enough to allow the unit to breach through the low density far minefield and then continue the attack without being encumbered by the slow moving breaching equipment. The low amount of breaching equipment also means that the majority of the force is able to engage the enemy while breaching operations are taking place.

The only configuration that clearly performs better than the 12/1/1 configuration is the 8/3/3. This configuration is of greater benefit when there is no direct fire and it is in these situations that the 8/3/3 configuration does perform better.

D. SENSITIVITY ANALYSIS USING THE ENHANCED MODEL

Sensitivity analysis was conducted through the use of the second model. As discussed in Chapter 3, the second model was developed using the concept of perfect communications. When one unit encounters a minefield, the rest of the units redeploy in formation 3, placing the roller assets in the lead to detect the minefields on their avenue. Two configurations, the 12/1/1 and the 10/2/2, were evaluated under two scenarios, the probability of minefields/direct fire and the 100% minefields/no direct fire, and the output was analyzed under the same MOEs and compared to the values found using Model 1. Table 7 shows the mean and standard deviation of the 50 repetitions conducted under each configuration and scenario.

The two configurations are compared against the base case configuration of 14/0/0. Figure 23 shows the comparison using MOE 1. In both configurations the performance using Model 1 was slightly better. However, using MOE 2, the losses due to mines was greatly reduced using Model 2, even to the point that the 12/1/1 configuration performed better than the 14/0/0 configuration (Figure 24). Figure 25 shows the total percent of losses due to both mines and direct fire. The configurations once again performed better under Model 2, even to the point that the 12/1/1 configuration suffered fewer losses than the 14/0/0 configuration in the probability of minefields/ direct fire scenario.

MOEs 4 (Figure 26), 5 (Figure 27), and 6 (Figure 28) compare the configurations when the amount of breaching equipment is constant. In all four cases the losses per piece of breaching equipment dropped under Model 2, however there was a slight increase in the direct fire losses. This can be attributed to the fact that once the first minefield is detected, the units move only as fast as the mineroller tank. Overall, the two configurations performed better under Model 2.

The percent of units assuming a defensive posture decreased under both scenarios of the 12/1/1 configuration, but the results were mixed for the 10/2/2 configuration (Figure 29). The period in the battle also showed an improvement for the 12/1/1 configuration under Model 2. In the probability of minefields/direct fire scenario, the number going to a defensive posture in the middle phase of the battle dropped dramatically, with a slight decrease occurring in the late battle also.

Once again the average length of battle figures are deceiving unless examined closely. Figure 31 show an increase in all the battle times. This is entirely due to the fact that once the first minefield is detected/detonated, the fastest speed a unit can move is that of the mineroller tank, at least until it is attritted.

Figure 32 shows the average ending range of the battle with the results indicating little or no difference between the two models. Finally, Figure 33 shows the rate of battle losses, again with a dramatic improvement for Model

2. Obviously the contributing factor is the decrease in losses to the force due to mine encounters.

The tactics used by the attacking force, in particular the method of detecting the obstacles, impacts heavily on the performance of the unit. Under Model 2 the 12/1/1 configuration once again performed better than the 10/2/2 configuration when evaluated under the two scenarios, because the majority of the breaching equipment is lost during the conduct of the first breach and the unit is able to travel faster. Also, under the probability of minefields/direct fire scenario, if one unit detects a minefield and is slowed in its progress, it will be able to easily catch up to the unit that did not encounter a minefield, since that unit is moving only as fast as the employed mineroller tank. This allows the units to align themselves to concentrate their fires on the target.

E. FINAL CONCLUSIONS

Based on the evaluation of the MOEs using the output from both Models 1 and 2 the following observations and conclusions can be made. The amount of breaching equipment required to support an armor battalion is situationally dependent.

The various factors weighing heavily on the required number of breaching assets are the enemy, terrain, mission and tactics. If a battalion is assigned a clearing mission in a lightly defended area, a force configured with a larger number of breaching assets would perform better, although if time was not crucial and the threat involved was low, a smaller number of breaching assets would prove to be just as effective.

If the area of operations is heavily defended, a force configuration that would allow the unit to breach the outer obstacles and then rapidly close with and defeat the enemy force would call for a smaller number of breaching assets. If the terrain restricts maneuver space to such a degree that the bypass option is no longer viable, the number of assets would have to be increased to insure a greater degree of success.

Based on the configurations and scenarios examined in this thesis, a force structure of 12 tanks, 1 mineplow and 1 mineroller tank is recommended, however further analysis in this area should be conducted to confirm the results.

UNIT 1 UNITCODE 1 EQUIP TANK 10 MINEPLOW 2 0 MINEROLLER 2 0
UNIT 2 UNITCODE 1 EQUIP TANK 10 MINEPLOW 2 0 MINEROLLER 2 0
UNIT 3 UNITCODE 1 EQUIP TANK 10 MINEPLOW 2 0 MINEROLLER 2 0
UNIT 4 UNITCODE 1 EQUIP TANK 10 MINEPLOW 2 0 MINEROLLER 2 0
NUMBER OF KILLS BY CATEGORY PER REPITITION

DIRECTFIRE	ROLL	PLOW	MINEFIELD	PLOWCARR	ROLLCARR	TOTKILL	CLOCK	MINRNG
40/30/ 3/ 7	1	0	5/ 5/ 0/ 0	4	0	49	54.5	1.278
25/20/ 2/ 3	1	0	5/ 5/ 0/ 0	5	2	37	47.5	1.014
15/11/ 1/ 3	2	0	8/ 8/ 0/ 0	2	0	25	41.0	0.803
19/12/ 5/ 2	0	0	0/ 0/ 0/ 0	2	0	21	40.0	1.228
16/11/ 3/ 2	0	0	4/ 4/ 0/ 0	1	0	21	40.5	1.303
20/16/ 2/ 2	3	0	10/10/ 0/ 0	6	0	36	46.5	1.581
17/10/ 1/ 6	1	0	7/ 7/ 0/ 0	2	0	26	42.5	1.588
23/15/ 3/ 5	1	0	2/ 2/ 0/ 0	1	0	26	43.0	0.711
17/14/ 2/ 1	3	0	4/ 4/ 0/ 0	3	0	24	42.0	0.933
27/17/ 4/ 6	2	0	5/ 5/ 0/ 0	4	0	36	49.5	0.877
20/14/ 3/ 3	5	1	16/16/ 0/ 0	4	0	40	46.0	1.414
23/14/ 4/ 5	1	0	3/ 3/ 0/ 0	1	0	27	41.0	2.141
22/14/ 1/ 7	0	0	1/ 1/ 0/ 0	4	1	28	45.5	0.643
23/16/ 3/ 4	1	0	1/ 1/ 0/ 0	1	0	25	44.0	0.651
13/12/ 0/ 1	3	0	1/ 1/ 0/ 0	4	0	18	43.0	1.113
20/17/ 2/ 1	1	0	4/ 4/ 0/ 0	3	2	29	45.0	0.936
9/ 5/ 2/ 2	0	0	1/ 1/ 0/ 0	0	0	10	35.5	1.525
16/12/ 1/ 3	1	0	1/ 1/ 0/ 0	4	1	22	43.0	0.799
15/ 9/ 3/ 3	1	0	5/ 5/ 0/ 0	2	1	23	41.5	1.105
30/24/ 2/ 4	4	1	10/10/ 0/ 0	5	0	45	50.5	0.910
29/19/ 3/ 7	0	0	6/ 6/ 0/ 0	1	0	36	44.0	0.794
20/13/ 3/ 4	1	0	7/ 7/ 0/ 0	2	3	32	48.0	0.937
8/ 6/ 2/ 0	0	0	1/ 1/ 0/ 0	0	0	9	37.5	1.236
28/21/ 3/ 4	2	0	6/ 6/ 0/ 0	3	1	38	47.5	1.005
8/ 7/ 0/ 1	2	2	2/ 2/ 0/ 0	3	0	13	40.5	1.374
31/23/ 3/ 5	1	0	3/ 3/ 0/ 0	3	1	38	49.0	0.889
17/12/ 1/ 4	0	0	3/ 3/ 0/ 0	4	0	24	42.0	1.110
20/17/ 2/ 1	7	1	13/13/ 0/ 0	5	0	38	50.0	0.356
19/13/ 3/ 3	2	0	1/ 1/ 0/ 0	3	1	24	42.0	0.944
14/ 9/ 2/ 3	1	0	4/ 4/ 0/ 0	3	0	21	40.5	1.152
22/15/ 2/ 5	1	0	2/ 2/ 0/ 0	1	0	25	43.0	0.866
20/16/ 1/ 3	3	0	6/ 6/ 0/ 0	7	2	35	49.0	1.101
23/16/ 3/ 4	0	0	3/ 3/ 0/ 0	3	0	29	42.5	1.119
22/14/ 3/ 5	1	0	2/ 2/ 0/ 0	3	1	28	41.5	1.479
9/ 5/ 1/ 3	1	0	1/ 1/ 0/ 0	0	0	10	38.0	1.349
11/ 8/ 2/ 1	0	0	4/ 4/ 0/ 0	0	0	15	42.0	1.009
16/ 9/ 2/ 5	0	0	2/ 2/ 0/ 0	1	0	19	42.0	1.087
20/16/ 1/ 3	3	0	13/13/ 0/ 0	7	2	42	53.5	1.265
20/16/ 0/ 4	1	0	1/ 1/ 0/ 0	4	0	25	43.5	0.966
26/19/ 2/ 5	0	0	1/ 1/ 0/ 0	1	0	28	44.0	1.104
16/11/ 1/ 4	1	0	1/ 1/ 0/ 0	2	0	19	41.5	1.178
15/11/ 0/ 4	1	1	4/ 4/ 0/ 0	1	1	21	42.0	0.914
15/10/ 2/ 3	0	0	1/ 1/ 0/ 0	2	1	19	42.0	0.963
20/13/ 3/ 4	0	0	4/ 4/ 0/ 0	1	0	25	43.0	1.108
18/12/ 2/ 4	0	0	2/ 2/ 0/ 0	3	0	23	42.5	1.197
12/ 7/ 1/ 4	0	0	3/ 3/ 0/ 0	2	0	17	40.5	1.337
10/ 8/ 0/ 2	0	0	2/ 2/ 0/ 0	3	0	15	42.0	1.131
24/19/ 2/ 3	2	0	2/ 2/ 0/ 0	2	0	28	43.5	1.502
.24/13/ 4/ 7	0	0	4/ 4/ 0/ 0	0	0	28	42.0	0.962
15/11/ 1/ 3	1	0	1/ 1/ 0/ 0	4	1	21	44.5	1.040

TABLE 1. VEHICLE LOSSES, TIME AND RANGE OUTPUT FILE

ACTIVE MINEFIELDS AND TIMES TO DEFENSIVE POSTURE

AVENUE 1			AVENUE 2			AVENUE 3			AVENUE 4			RUN TIME
M1	M2		M1	M2		M1	M2		M1	M2		
1	1	46.0	1	1	34.5	1	1	49.5	1	1	41.0	60.5
1	1	0.0	1	0	0.0	0	1	41.0	1	0	0.0	42.5
1	1	0.0	1	1	36.5	1	0	0.0	0	1	0.0	42.5
1	1	0.0	0	1	0.0	0	1	37.0	1	1	0.0	43.5
0	1	0.0	1	1	0.0	0	1	0.0	1	1	0.0	42.5
1	0	0.0	1	1	40.5	0	1	0.0	0	1	0.0	42.0
0	1	0.0	1	1	40.0	1	1	0.0	0	1	0.0	40.5
1	1	40.0	1	1	40.0	1	1	43.0	0	0	0.0	45.5
1	1	0.0	0	0	42.0	1	1	35.5	1	1	0.0	43.0
1	1	0.0	1	1	40.0	0	1	0.0	0	1	0.0	42.5
1	1	43.5	1	1	41.5	1	1	38.5	1	1	42.5	45.0
0	1	0.0	1	1	0.0	0	1	0.0	0	1	0.0	39.0
0	0	0.0	1	1	45.0	1	1	36.5	1	1	47.5	49.0
1	1	0.0	0	1	0.0	0	1	36.5	1	1	0.0	45.5
1	1	0.0	1	0	0.0	0	1	0.0	1	1	0.0	42.5
0	1	0.0	1	1	38.0	1	1	40.0	1	1	0.0	44.0
1	1	0.0	0	1	0.0	1	1	36.0	1	1	0.0	39.5
0	1	0.0	0	1	0.0	1	1	36.5	0	1	0.0	41.0
0	1	0.0	1	1	0.0	0	1	0.0	1	1	0.0	43.0
1	1	0.0	0	1	0.0	1	1	37.0	1	1	0.0	43.0
0	1	0.0	1	1	0.0	0	0	0.0	1	1	0.0	40.5
1	1	0.0	1	1	0.0	0	1	0.0	1	0	0.0	44.0
1	1	0.0	1	1	0.0	1	1	36.5	0	1	0.0	41.0
1	0	40.5	1	1	33.5	0	0	38.5	1	1	0.0	41.0
1	1	0.0	1	1	0.0	0	1	38.0	0	1	0.0	41.5
1	1	0.0	1	1	0.0	0	1	37.0	1	0	0.0	43.0
1	1	0.0	0	1	0.0	0	1	0.0	1	1	0.0	40.5
1	1	41.5	1	0	37.5	1	0	38.5	1	1	46.0	49.0
1	1	0.0	0	0	0.0	1	1	45.0	1	1	0.0	46.0
1	1	0.0	0	1	0.0	1	1	0.0	0	0	0.0	40.5
1	1	0.0	1	1	0.0	0	1	0.0	0	1	0.0	43.5
1	1	0.0	0	1	0.0	1	1	0.0	0	1	0.0	35.5
0	1	0.0	1	1	36.0	1	1	36.5	0	1	0.0	40.5
1	1	0.0	0	1	0.0	1	1	0.0	1	1	0.0	41.5
1	1	0.0	1	1	36.5	1	1	37.5	0	1	0.0	46.5
1	1	0.0	0	1	0.0	0	0	40.0	0	1	0.0	43.5
1	1	0.0	1	1	0.0	1	1	38.0	0	1	0.0	45.5
1	1	0.0	1	1	0.0	0	1	38.5	0	1	0.0	42.0
1	0	0.0	1	1	0.0	1	0	38.0	0	1	0.0	42.5
1	1	0.0	0	0	0.0	0	1	0.0	1	0	0.0	38.0
0	1	0.0	1	1	0.0	0	1	40.5	0	1	0.0	46.0
1	0	39.0	1	1	39.0	1	1	35.5	1	1	0.0	41.5
1	1	0.0	0	1	45.5	1	1	33.0	0	1	44.5	46.0
1	1	0.0	0	0	0.0	1	1	36.5	1	1	0.0	42.0
1	1	0.0	0	1	0.0	1	1	35.5	0	0	0.0	42.0
1	1	41.5	1	1	43.0	1	1	38.0	1	1	0.0	44.5
1	1	38.0	0	1	41.5	0	1	40.5	0	1	0.0	42.0
1	0	0.0	1	1	40.5	1	1	35.5	1	1	0.0	43.5
1	1	0.0	0	1	0.0	1	1	0.0	0	1	0.0	37.5
1	0	0.0	1	1	0.0	0	1	0.0	1	1	0.0	43.5

TABLE 2. MINEFIELD STATUS AND DEFENSIVE POSTURE TIME OUTPUT FILE

No Minefields/Direct Fire

Unit Configuration

Measure of Effectiveness	14/0/0	12/1/1	10/2/2	8/3/3	10/3/1
1	0.239 (0.098)	0.251 (0.100)	0.252 (0.099)	0.268 (0.105)	0.235 (0.092)
2	N/A	N/A	N/A	N/A	N/A
3	0.239 (0.098)	0.251 (0.098)	0.252 (0.099)	0.268 (0.105)	0.235 (0.092)
4	N/A	N/A	N/A	N/A	N/A
5	N/A	7.020 (2.808)	3.525 (1.384)	2.500 (0.983)	3.295 (1.291)
6	N/A	7.020 (2.808)	3.525 (1.384)	2.500 (0.983)	3.295 (1.291)
7	16/200	21/200	14/200	20/200	13/200
8	0 0 0 16	0 0 0 21	0 0 0 14	0 0 0 20	0 0 0 13
9	24.21 (0.969)	36.80 (1.484)	36.85 (1.543)	36.92 (1.592)	36.28 (1.614)
10	0.773 (0.227)	1.047 (0.242)	1.045 (0.271)	1.050 (0.267)	1.127 (0.294)
11	0.548 (0.204)	0.378 (0.139)	0.379 (0.136)	0.402 (0.144)	0.359 (0.128)

TABLE 3. NO MINEFIELDS/DIRECT FIRE STATISTICS

Prob Minefields/Direct Fire

Unit Configuration

Measure of Effectiveness

	14/0/0	12/1/1	10/2/2	8/3/3	10/3/1
1	0.338 (0.127)	0.292 (0.105)	0.328 (0.147)	0.317 (0.133)	0.308 (0.430)
2	0.105 (0.064)	0.153 (0.076)	0.170 (0.087)	0.160 (0.084)	0.174 (0.085)
3	0.444 (0.152)	0.446 (0.144)	0.498 (0.181)	0.477 (0.173)	0.482 (0.184)
4	N/A	4.300 (2.126)	2.380 (1.220)	1.493 (0.782)	2.435 (1.195)
5	N/A	8.190 (2.948)	4.590 (2.056)	2.963 (1.246)	4.320 (1.997)
6	N/A	12.49 (4.039)	6.970 (2.538)	4.457 (1.613)	6.755 (2.570)
7	74/200	71/200	77/200	85/200	81/200
8	1 4 27 42	0 0 10 61	0 4 12 61	0 0 11 84	0 12 4 65
9	33.87 (11.37)	40.02 (5.372)	41.63 (9.287)	40.45 (5.358)	42.70 (13.29)
10	2.096 (3.742)	1.098 (0.300)	1.015 (0.335)	1.026 (0.305)	1.062 (0.292)
11	0.737 (0.160)	0.615 (0.153)	0.660 (0.148)	0.648 (0.184)	0.629 (0.151)

TABLE 4. PROBABILITY OF MINEFIELDS/DIRECT FIRE STATISTICS

100% Minefields/Direct Fire

Unit Configuration

Measure of Effectiveness	14/0/0	12/1/1	10/2/2	8/3/3	10/3/1
1	0.401 (0.150)	0.357 (0.150)	0.385 (0.124)	0.381 (0.169)	0.361 (0.142)
2	0.187 (0.070)	0.258 (0.078)	0.253 (0.053)	0.236 (0.056)	0.265 (0.064)
3	0.589 (0.170)	0.615 (0.172)	0.639 (0.135)	0.616 (0.185)	0.626 (0.157)
4	N/A	7.230 (2.174)	3.550 (0.739)	2.203 (0.526)	3.705 (0.896)
5	N/A	9.990 (4.198)	5.395 (1.736)	3.553 (1.579)	5.060 (1.989)
6	N/A	17.22 (4.319)	8.945 (2.056)	5.757 (1.730)	8.765 (2.193)
7	124/200	131/200	145/200	142/200	152/200
8	2 21 50 50	0 11 24 96	0 14 12 119	0 10 24 108	0 8 28 116
9	46.14 (14.68)	46.90 (12.52)	47.00 (13.34)	46.27 (12.49)	46.18 (11.42)
10	1.617 (0.445)	1.314 (0.305)	1.045 (0.369)	1.022 (0.373)	1.030 (0.378)
11	0.729 (0.161)	0.740 (0.114)	0.771 (0.102)	0.744 (0.137)	0.762 (0.113)

TABLE 5. 100% MINEFIELDS/DIRECT FIRE STATISTICS

100% Minefields/No Direct Fire

Unit Configuration

Measure of Effectiveness	14/0/0	12/1/1	10/2/2	8/3/3	10/3/1
1	N/A	N/A	N/A	N/A	N/A
2	0.213 (0.052)	0.346 (0.093)	0.356 (0.080)	0.321 (0.062)	0.368 (0.080)
3	0.213 (0.052)	0.346 (0.093)	0.356 (0.080)	0.321 (0.062)	0.368 (0.080)
4	N/A	9.700 (2.619)	4.990 (1.116)	2.997 (0.578)	5.155 (1.126)
5	N/A	N/A	N/A	N/A	N/A
6	N/A	9.700 (2.619)	4.990 (1.116)	2.997 (0.578)	5.155 (1.126)
7	2/200	44/200	35/200	14/200	35/200
8	0 2 0 0	0 0 15 29	0 0 0 35	0 0 0 14	0 0 0 35
9	62.83 (4.738)	49.91 (7.878)	44.15 (1.408)	44.08 (0.798)	43.92 (1.153)
10	0.218 (0.022)	0.217 (0.027)	0.215 (0.028)	0.214 (0.024)	0.214 (0.022)
11	0.192 (0.056)	0.396 (0.119)	0.452 (0.102)	0.409 (0.083)	0.470 (0.105)

TABLE 6. 100% MINEFIELDS NO DIRECT FIRE STATISTICS

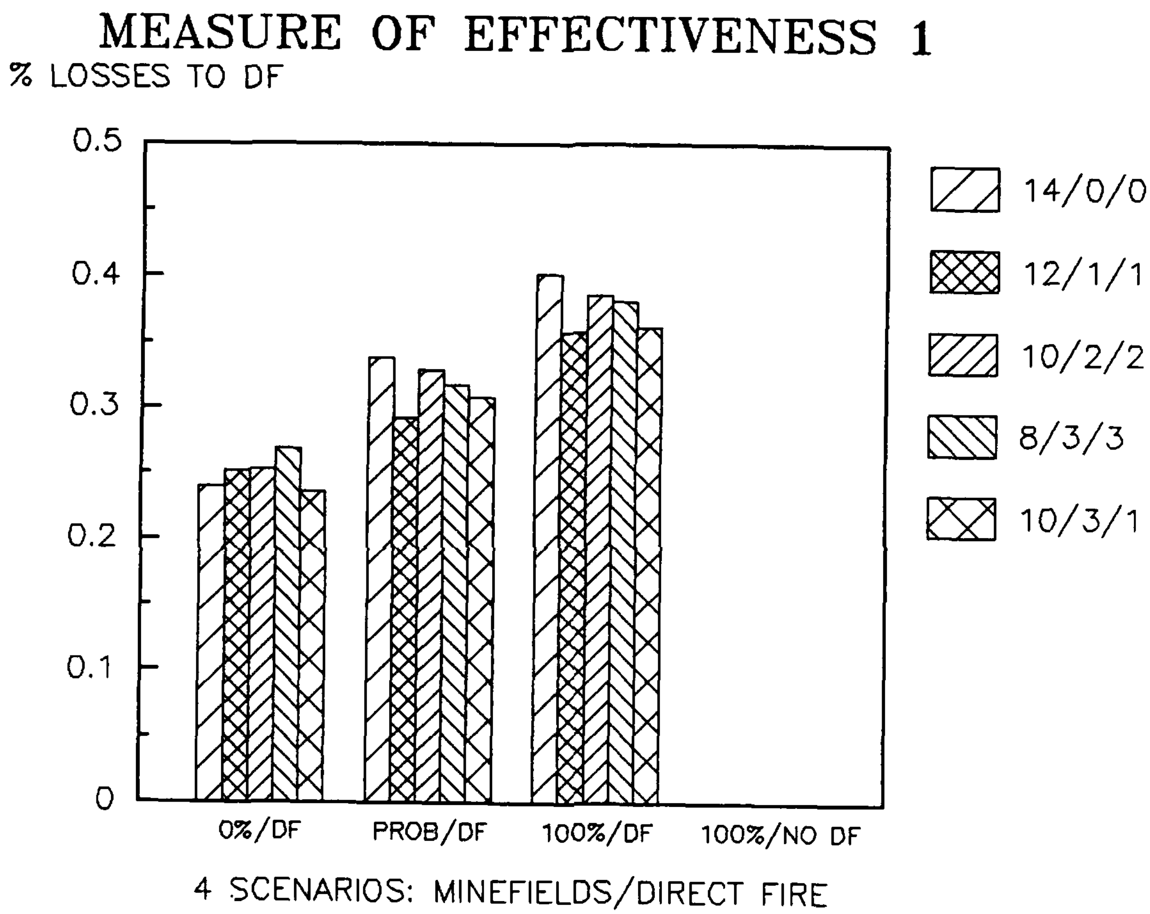


Figure 12. Model 1 Measure of Effectivess 1

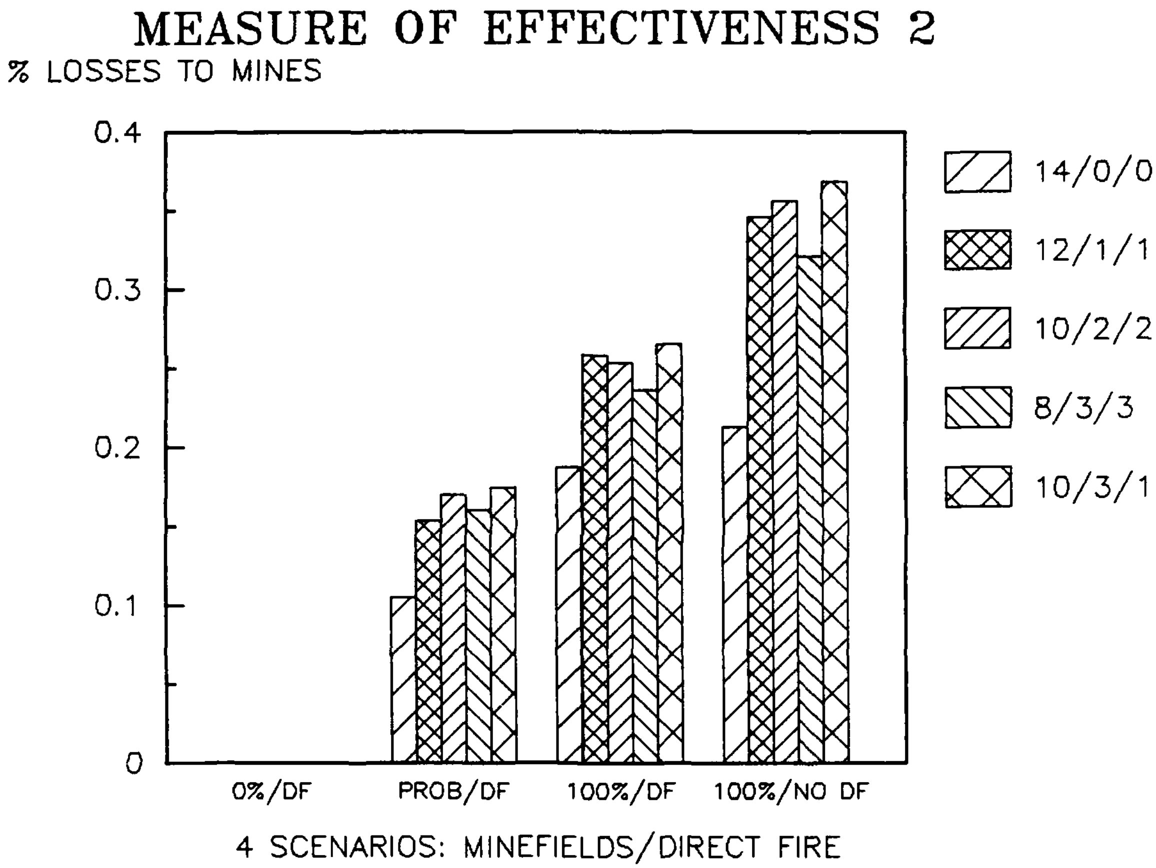


Figure 13. Model 1 Measure of Effectiveness 2

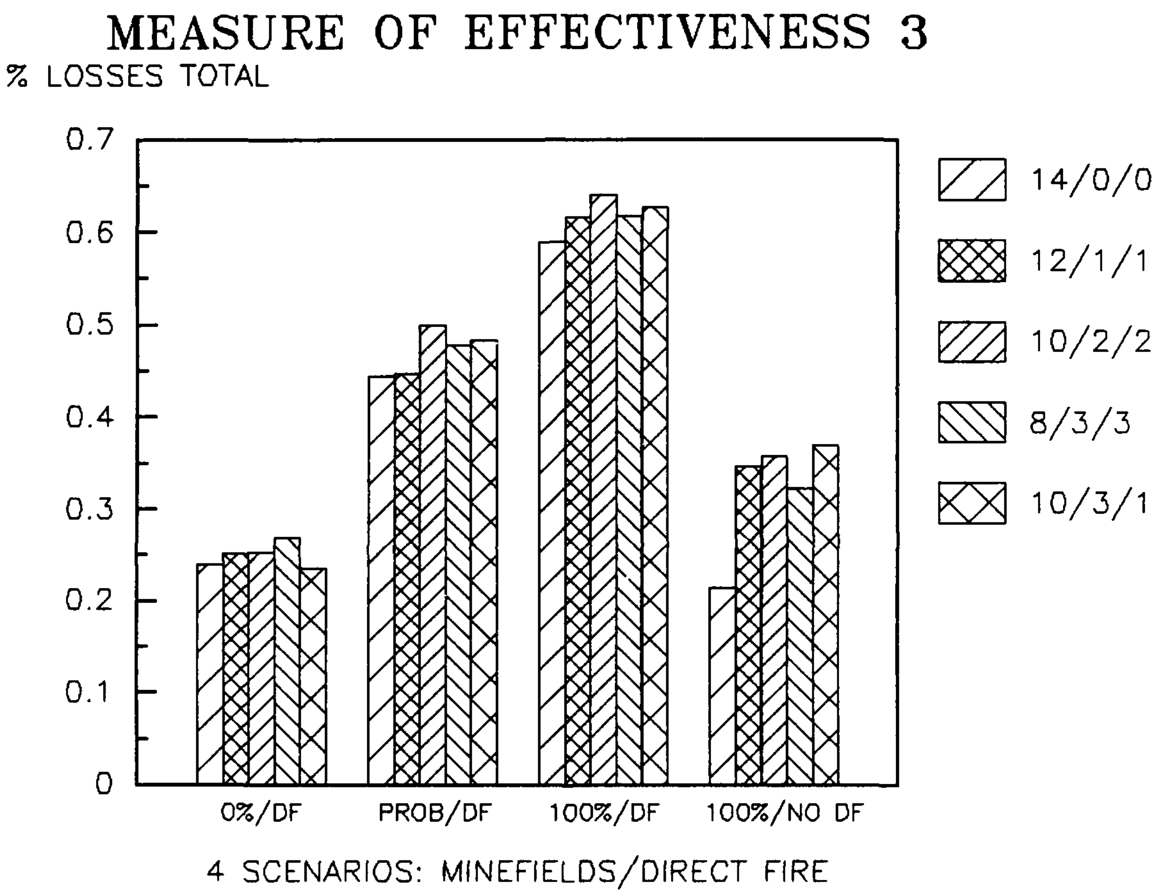


Figure 14. Model 1 Measure of Effectiveness 3

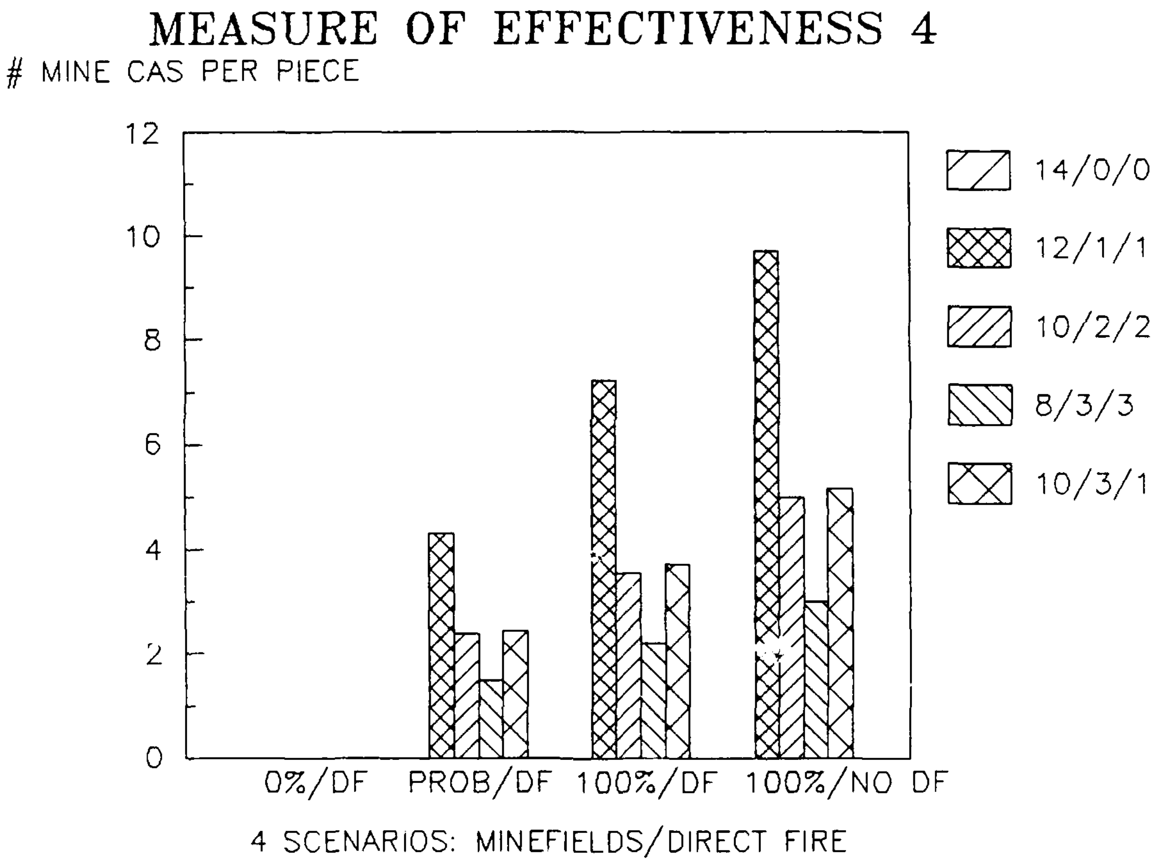


Figure 15. Model 1 Measure of Effectiveness 4

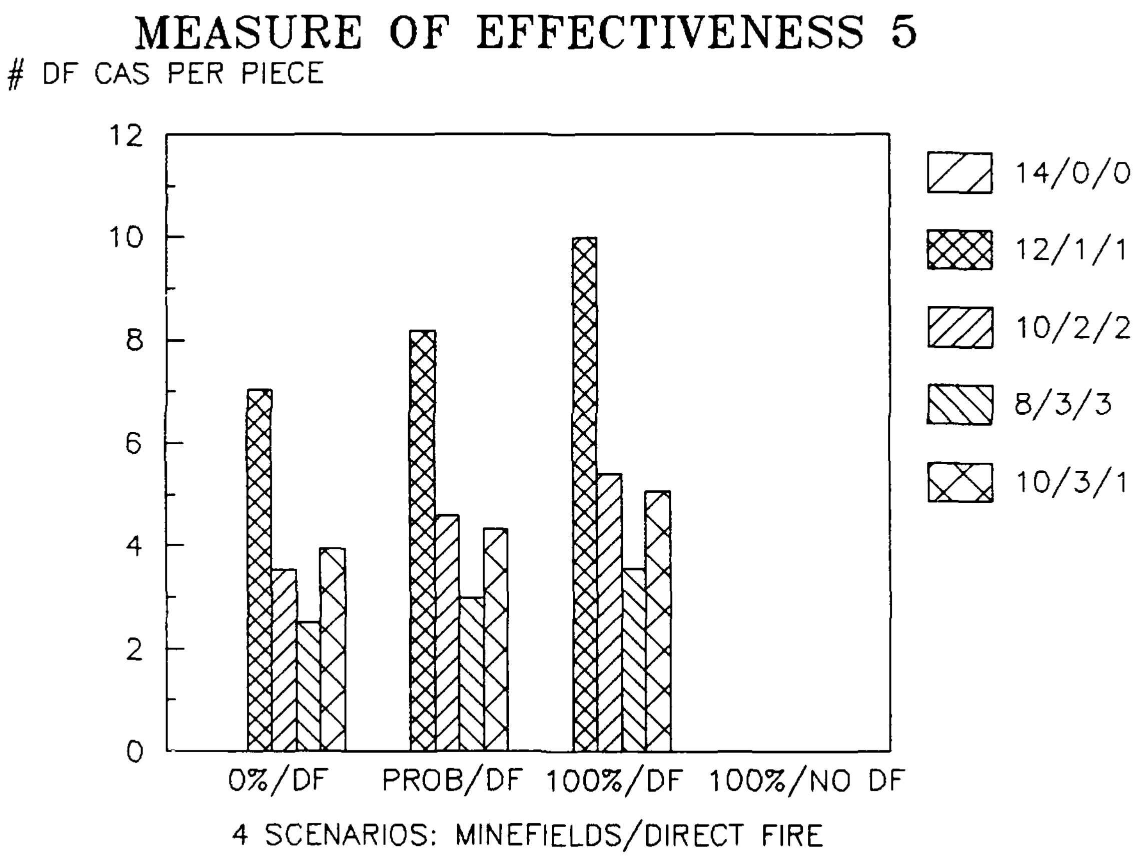


Figure 16. Model 1 Measure of Effectiveness 5

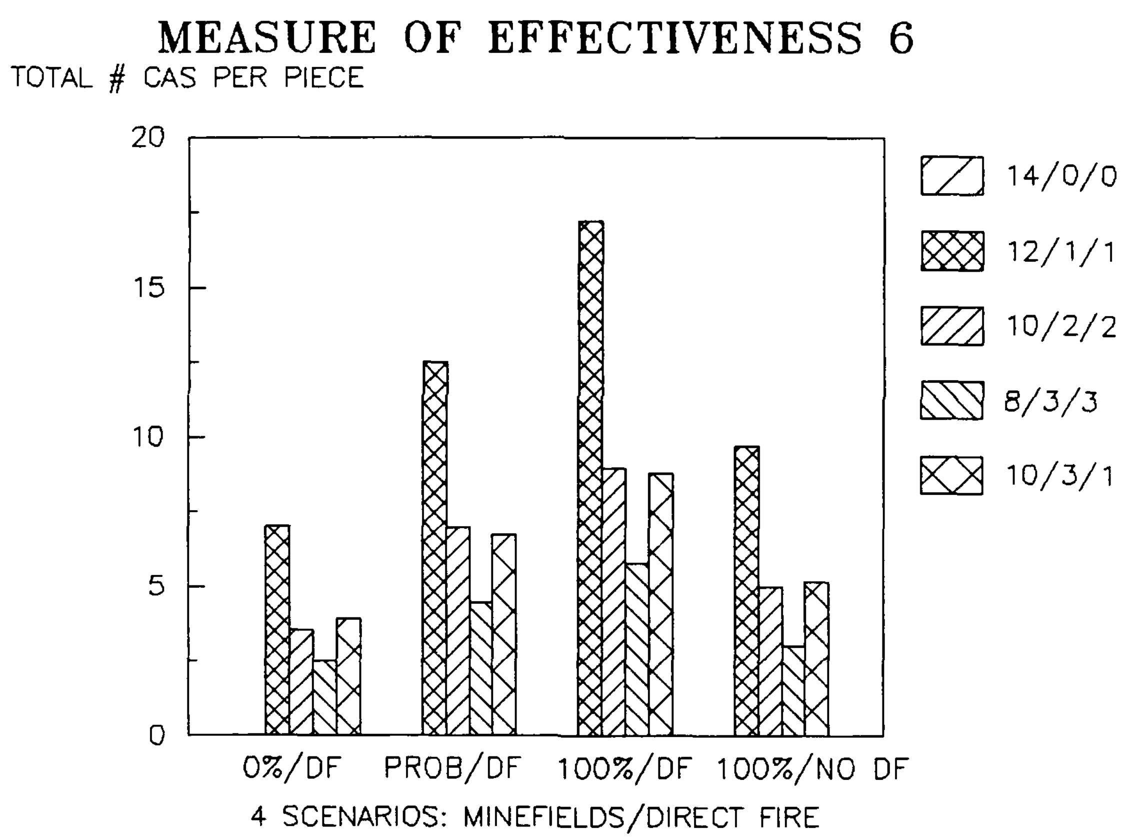


Figure 17. Model 1 Measure of Effectiveness 6

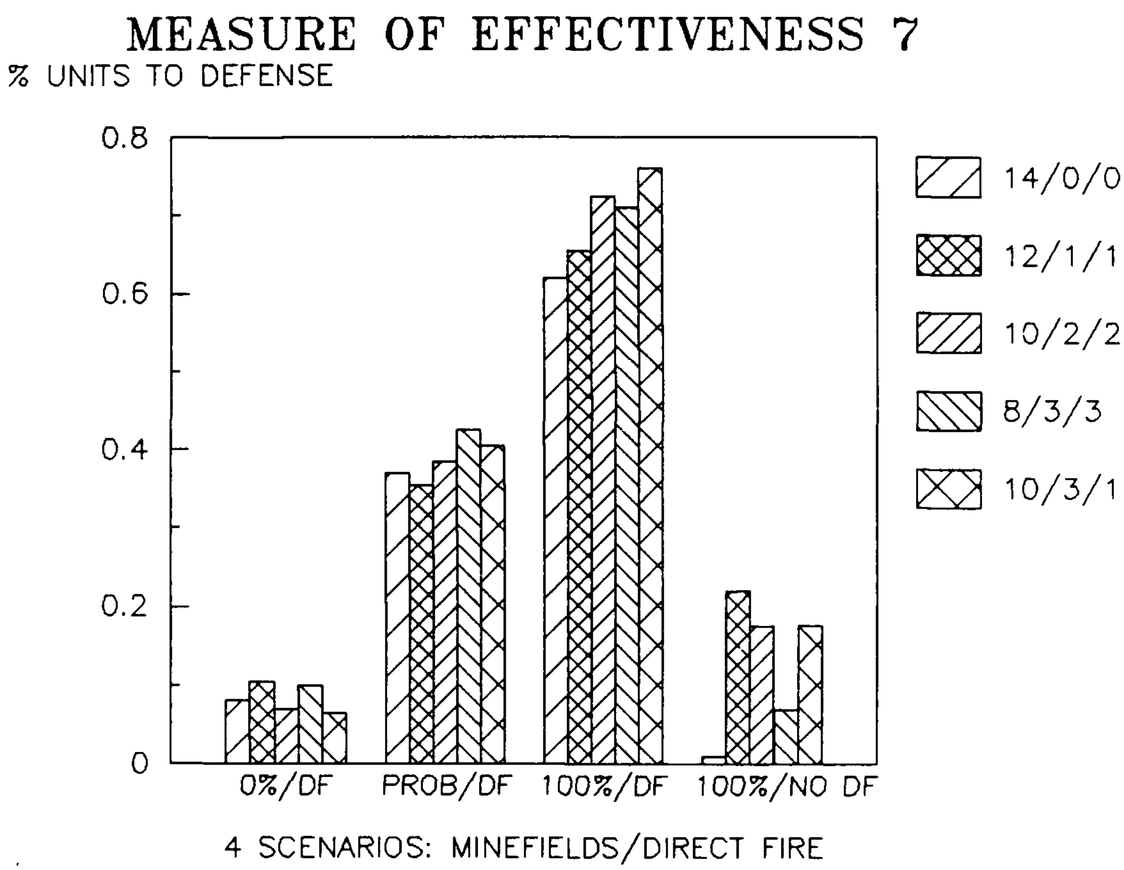


Figure 18. Measure of Effectiveness 7

MEASURE OF EFFECTIVENESS 8

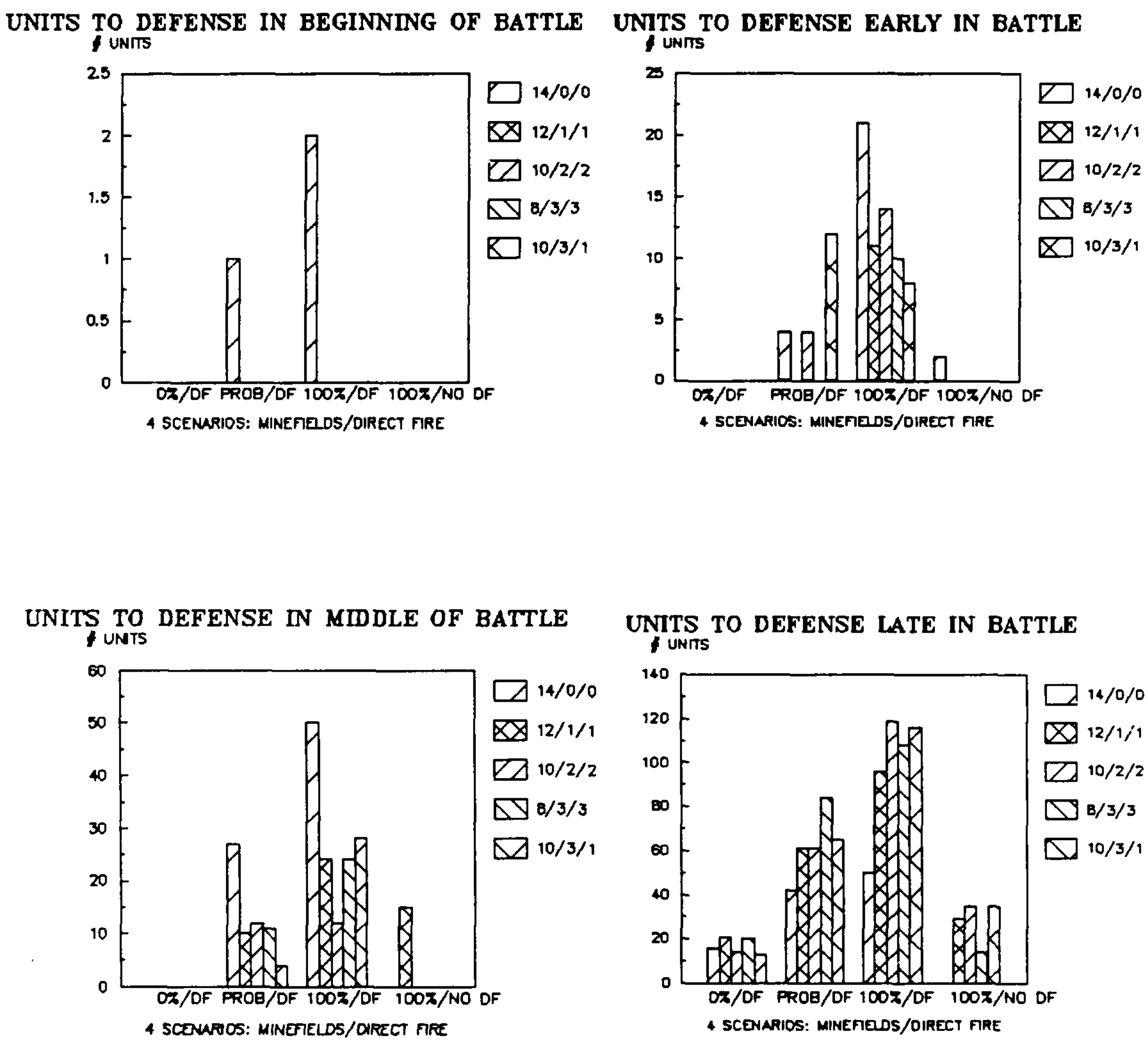


Figure 19. Model 1 Measure of Effectiveness 8

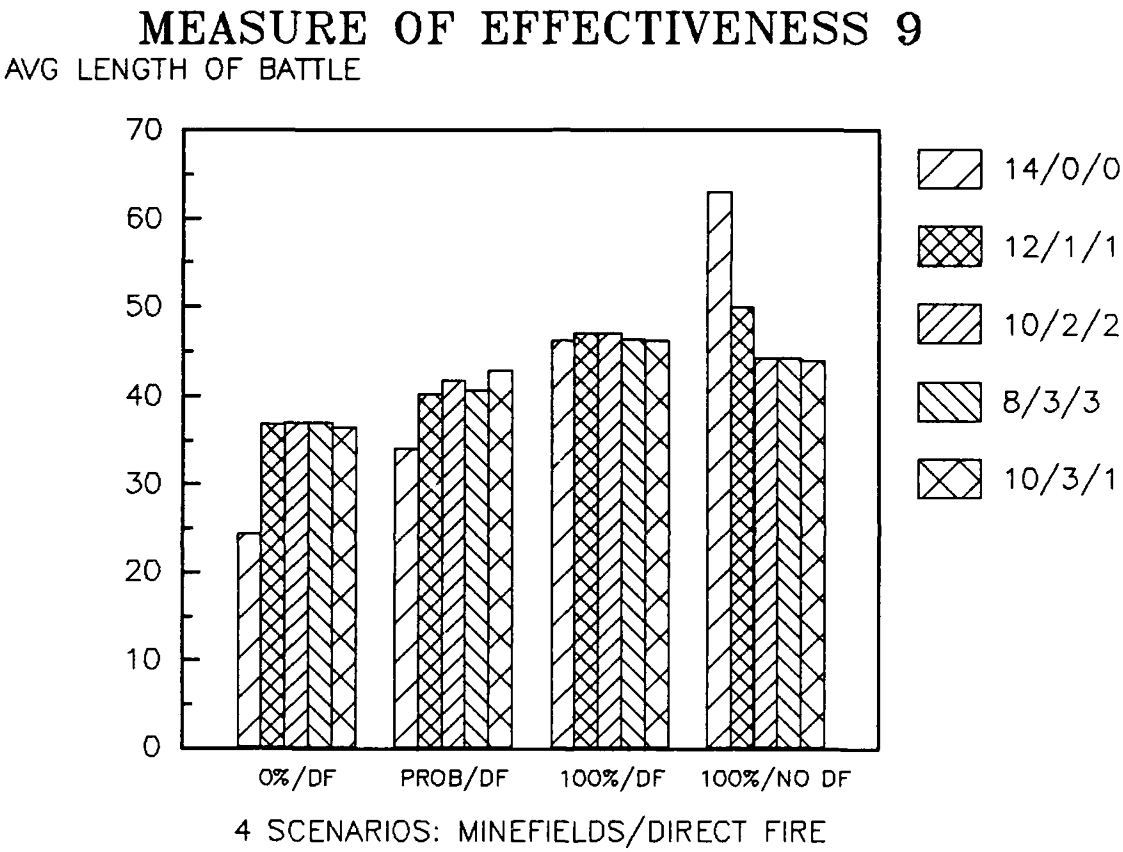


Figure 20. Model 1 Measure of Effectiveness 9

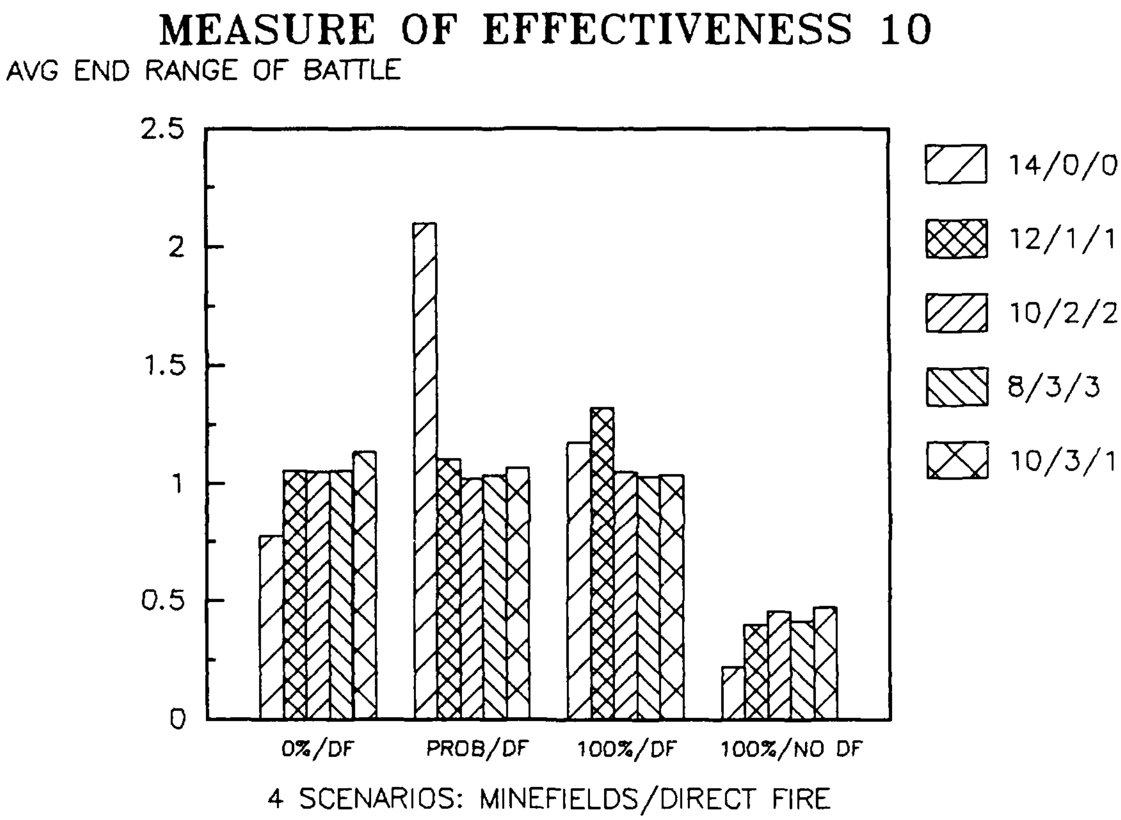


Figure 21. Model 1 Measure of Effectiveness 10

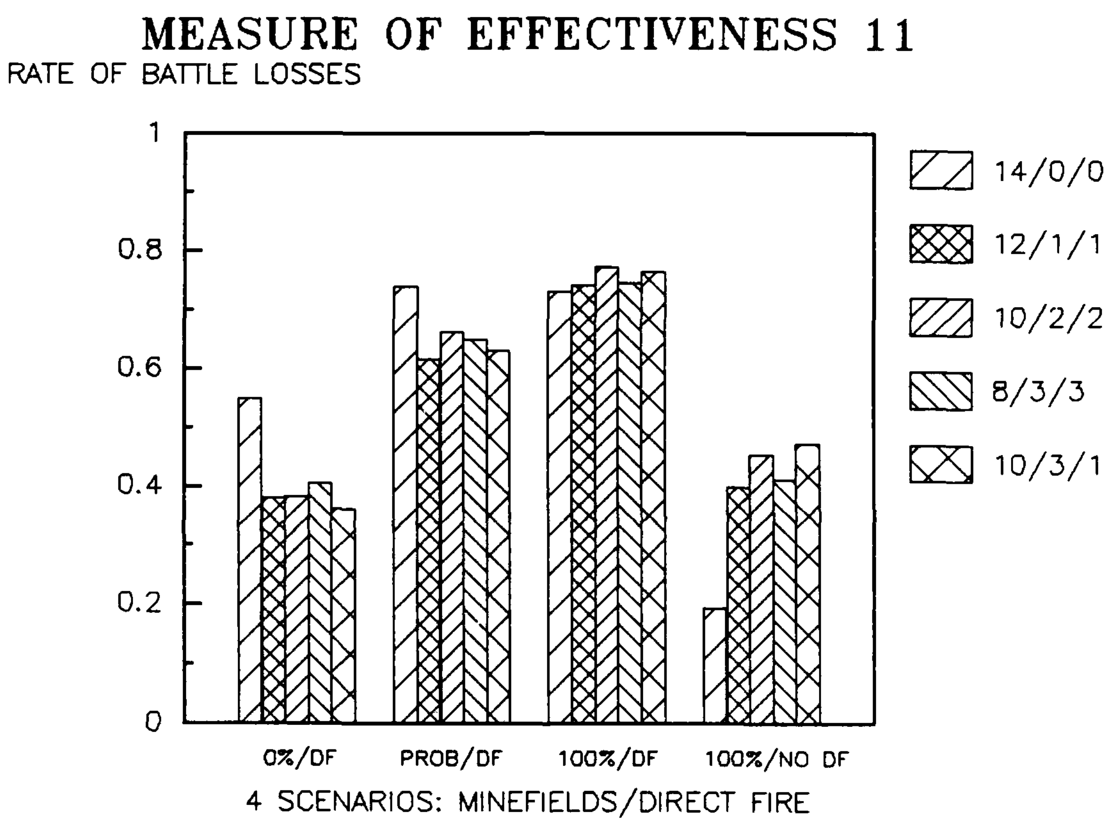


Figure 22. Model 1 Measure of Effectiveness 11

MODEL 2 STATISTICS

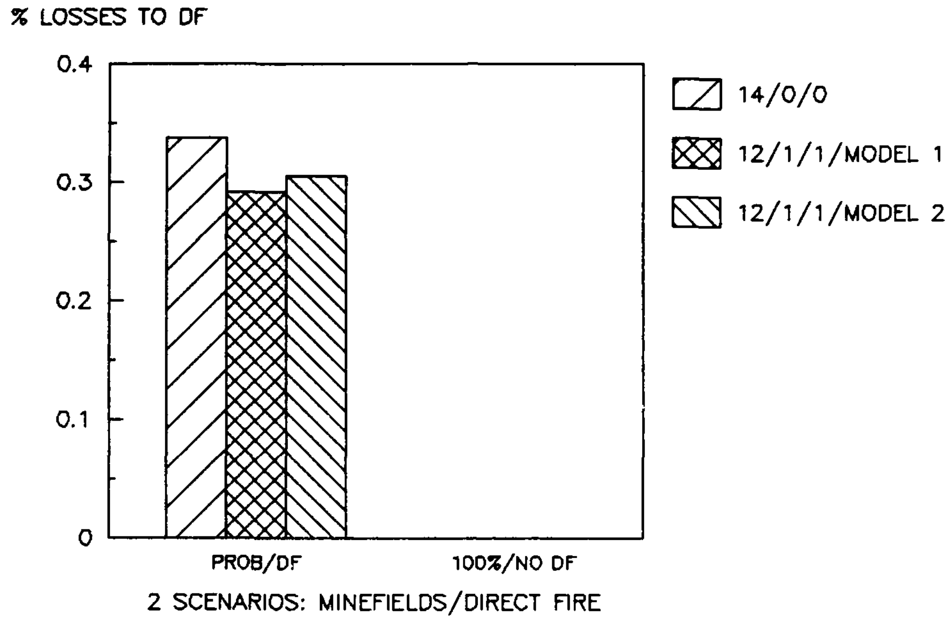
Unit Configuration

Measure of Effectiveness

	12/1/1 PROB/DF	12/1/1 100%/ NO DF		10/2/2 PROB/DF	10/2/2 100%/ NO DF
1	0.305 (0.112)	N/A		0.343 (0.114)	N/A
2	0.098 (0.054)	0.241 (0.102)		0.125 (0.086)	0.257 (0.973)
3	0.403 (0.134)	0.241 (0.102)		0.469 (0.162)	0.257 (0.973)
4	2.760 (1.532)	6.750 (2.856)		1.755 (1.207)	3.600 (1.363)
5	8.540 (3.134)	N/A		4.810 (1.601)	N/A
6	11.30 (3.751)	6.750 (2.856)		6.565 (2.267)	3.600 (1.363)
7	64/200	35/200		91/200	32/200
8	0 0 4 60	0 0 20 15		0 0 6 85	0 0 0 32
9	43.02 (3.620)	55.18 (7.512)		43.71 (3.805)	48.44 (2.251)
10	1.084 (0.438)	0.223 (0.022)		1.122 (0.297)	0.219 (0.027)
11	0.518 (0.144)	0.245 (0.101)		0.590 (0.161)	0.298 (0.112)

TABLE 7 MODEL 2 STATISTICS

MEASURE OF EFFECTIVENESS 1
MODEL 1 VERSUS MODEL 2



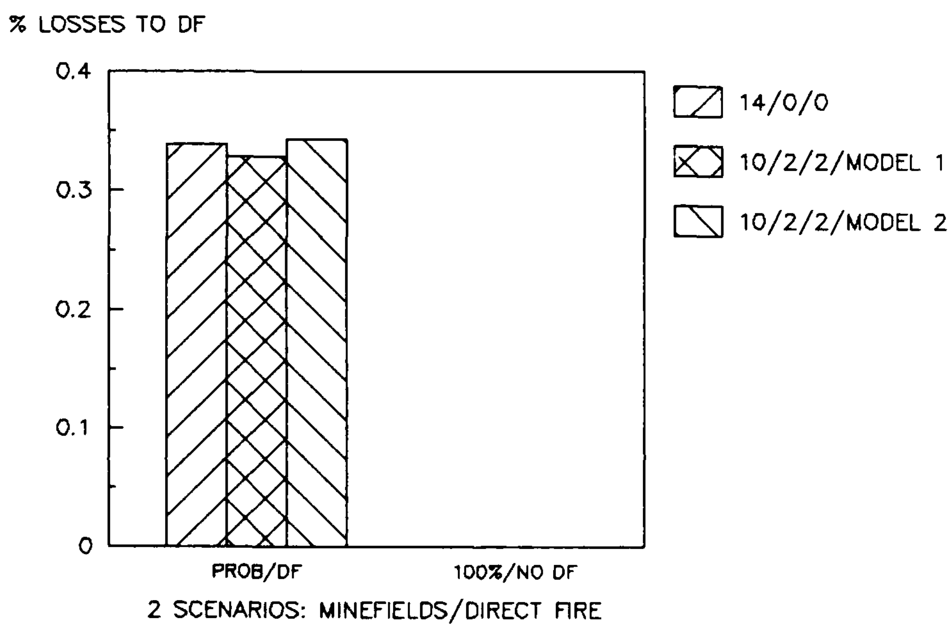


Figure 23. Model 1 versus Model 2
Measure of Effectiveness 1

MEASURE OF EFFECTIVENESS 2
MODEL 1 VERSUS MODEL 2

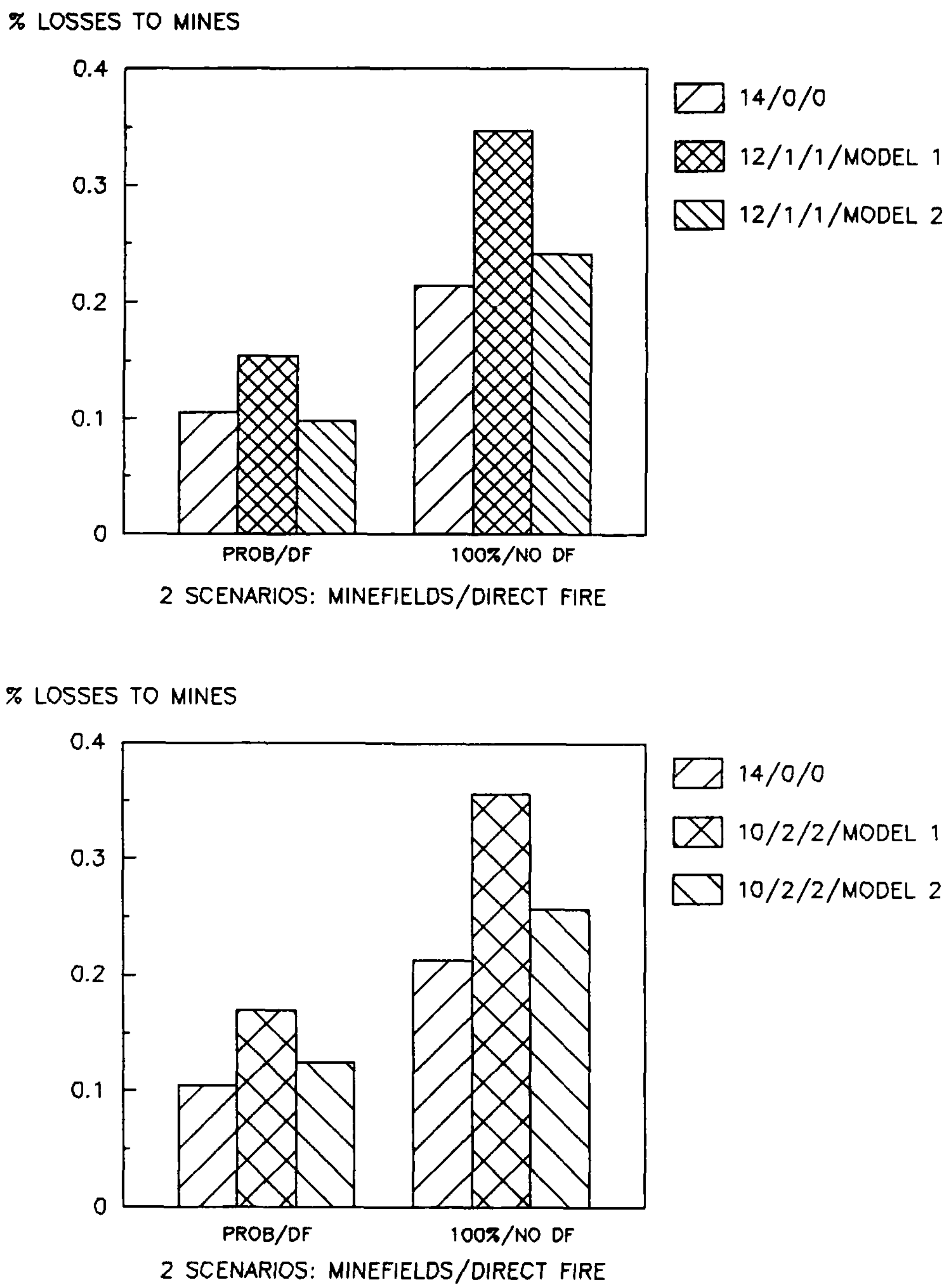
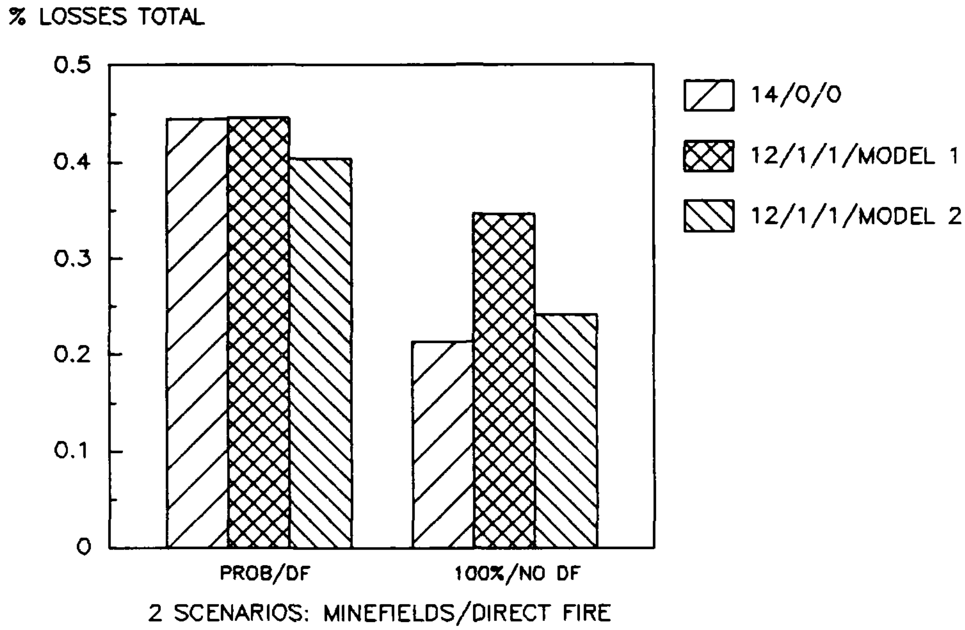


Figure 24. Model 1 versus Model 2
Measure of Effectiveness 2

MEASURE OF EFFECTIVENESS 3
MODEL 1 VERSUS MODEL 2



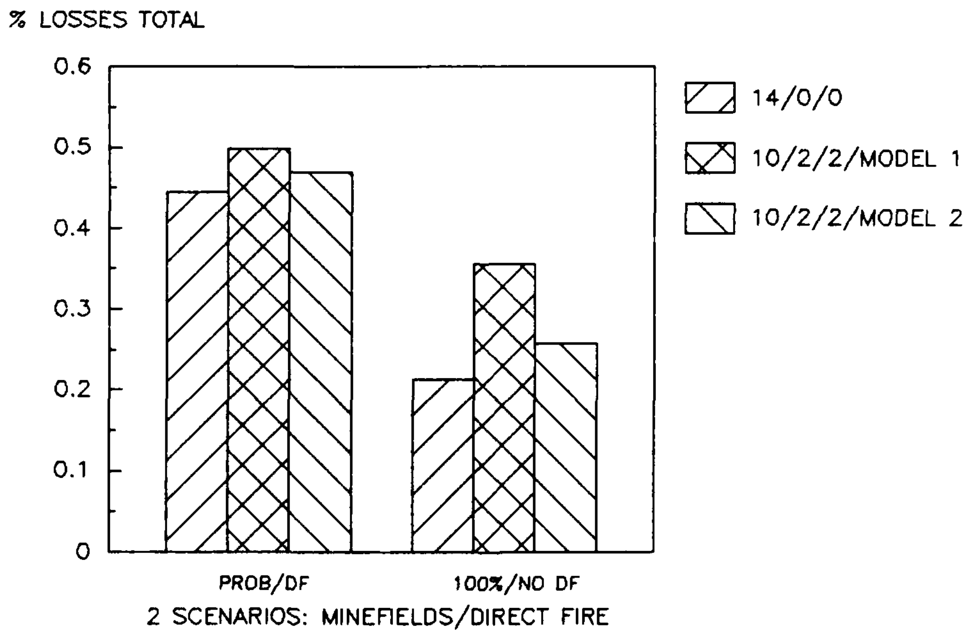


Figure 25. Model 1 versus Model 2
Measure of Effectiveness 3

MEASURE OF EFFECTIVENESS 4
MODEL 1 VERSUS MODEL 2

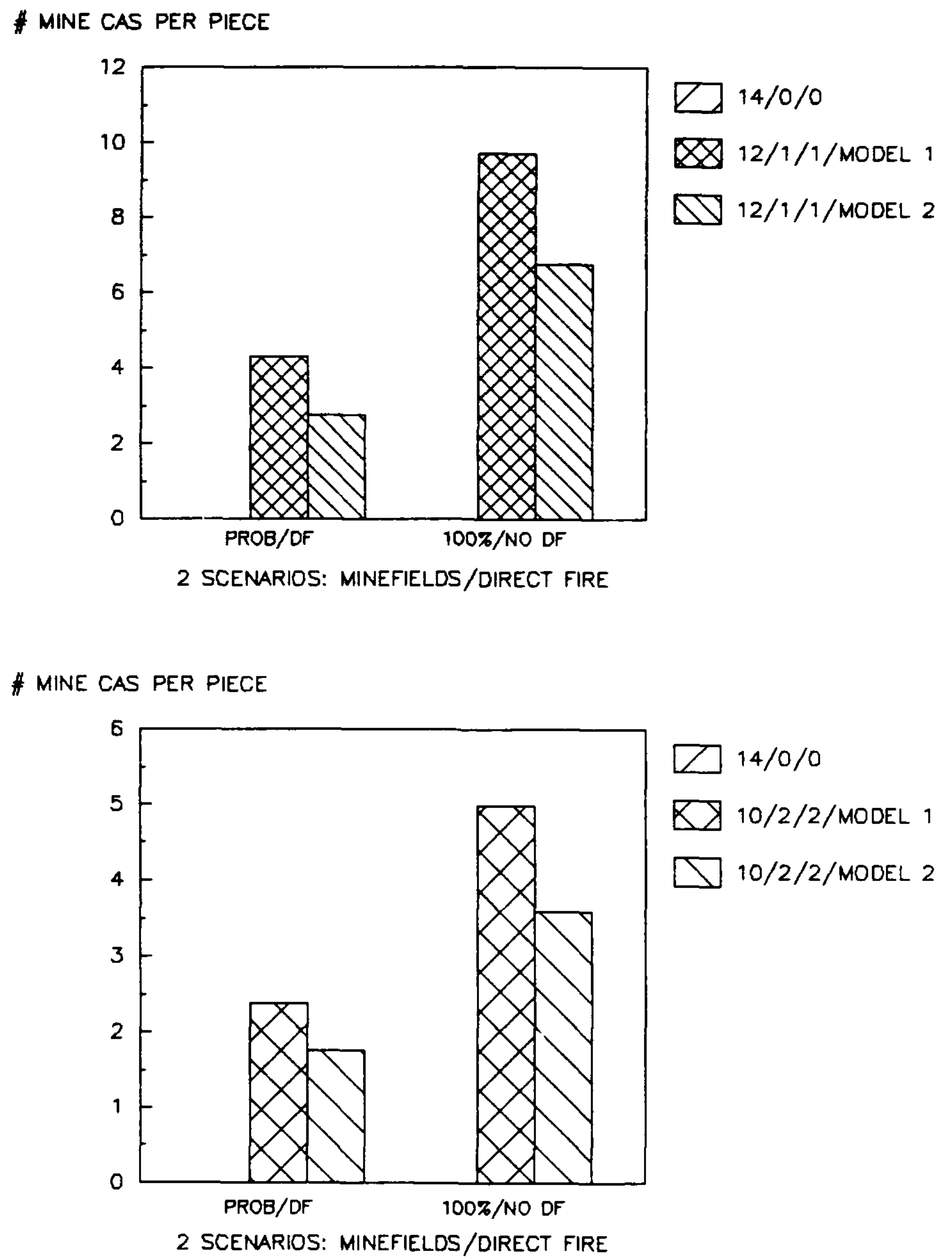
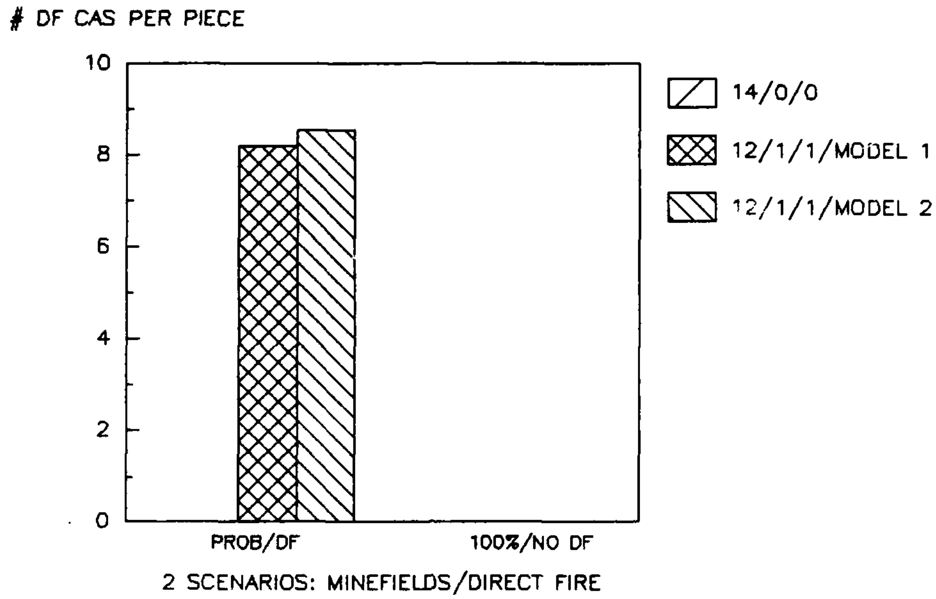


Figure 26. Model 1 versus Model 2
Measure of Effectiveness 4

MEASURE OF EFFECTIVENESS 5
MODEL 1 VERSUS MODEL 2



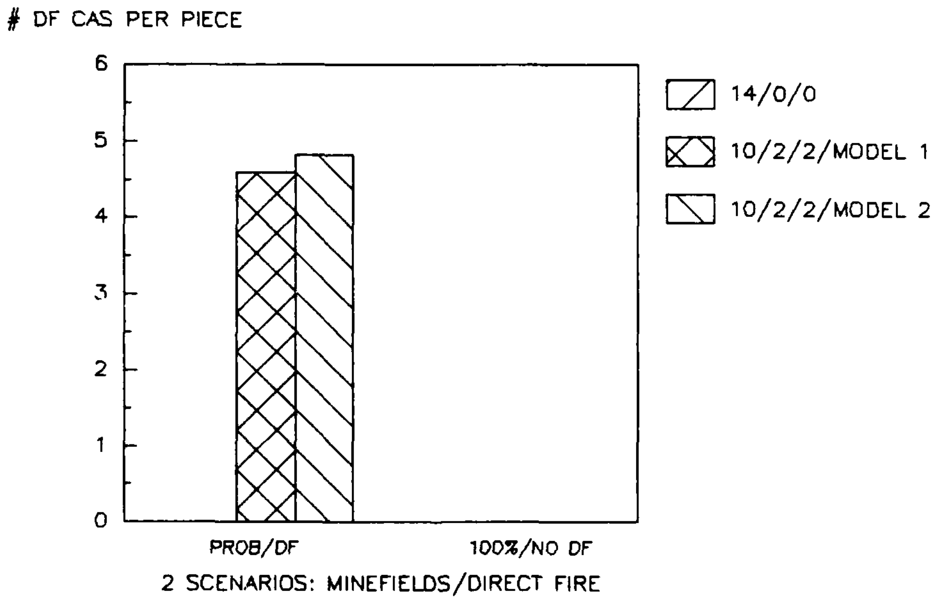
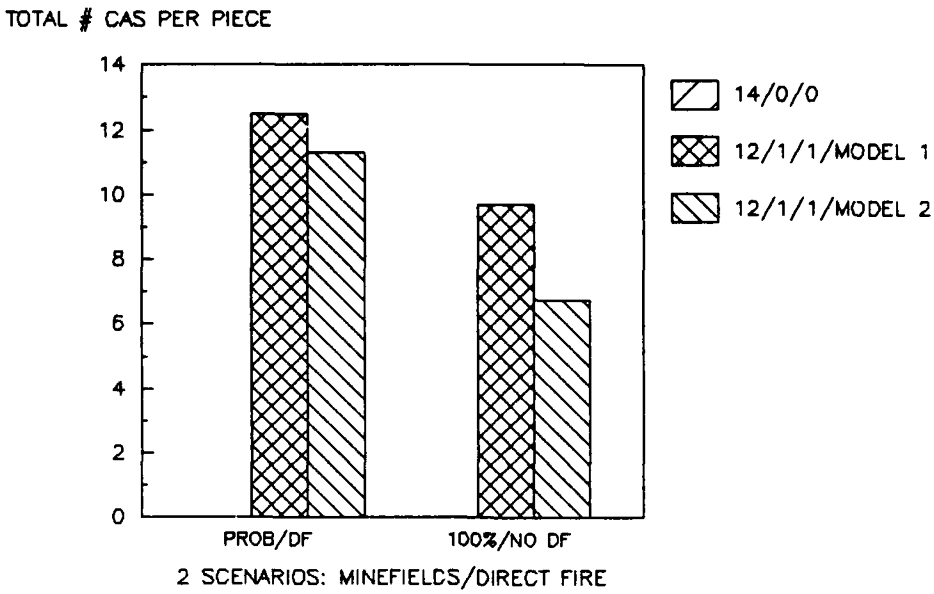


Figure 27. Model 1 versus Model 2
Measure of Effectiveness 5

MEASURE OF EFFECTIVENESS 6
MODEL 1 VERSUS MODEL 2



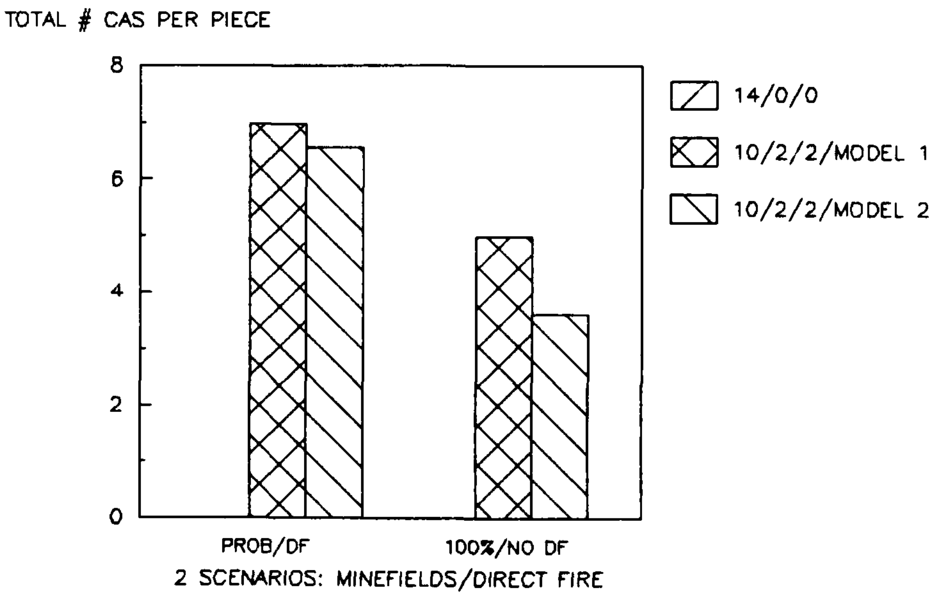
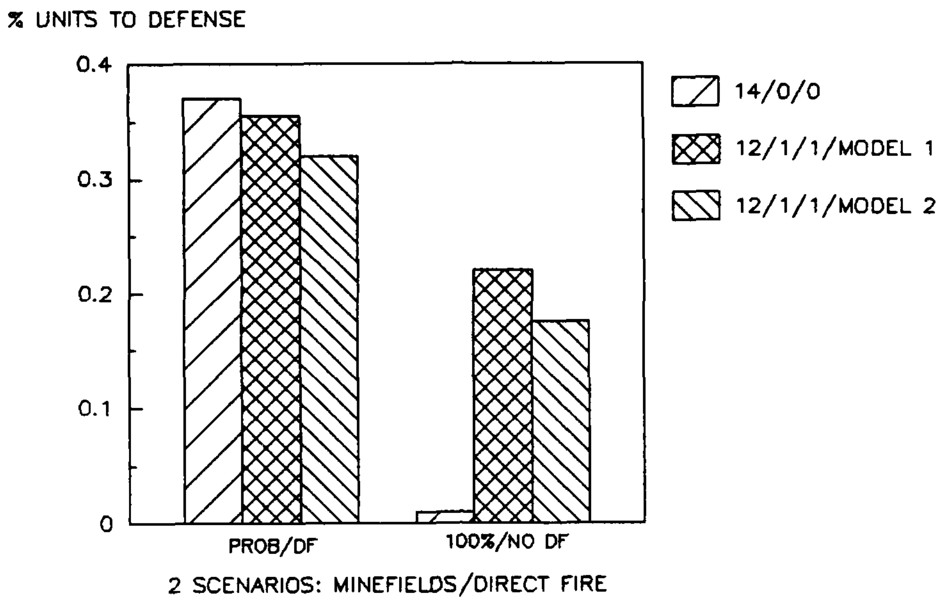


Figure 28. Model 1 versus Model 2
Measure of Effectiveness 6

MEASURE OF EFFECTIVENESS 7
MODEL 1 VERSUS MODEL 2



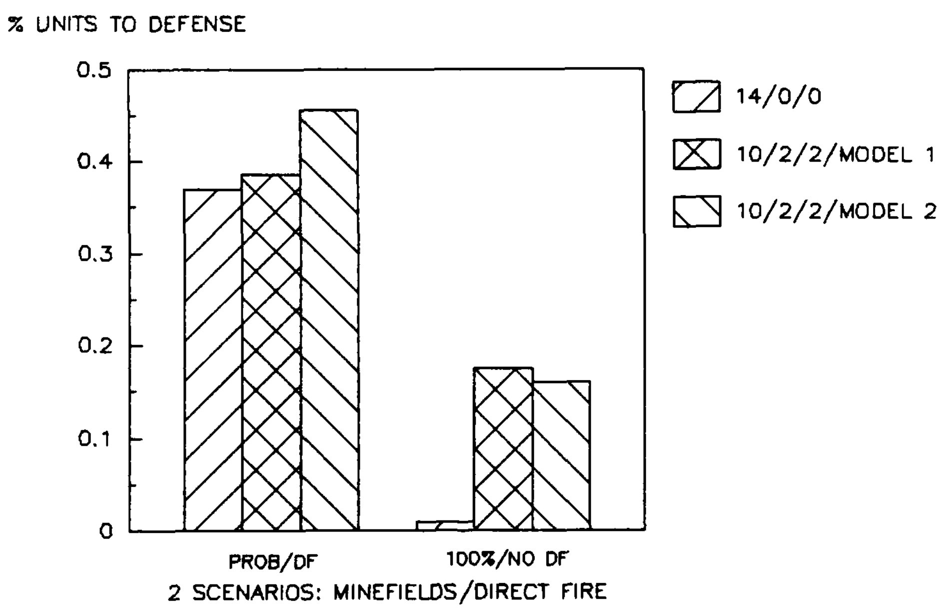


Figure 29. Model 1 versus Model 2
Measure of Effectiveness 7

MEASURE OF EFFECTIVENESS 8
MODEL 1 VERSUS MODEL 2

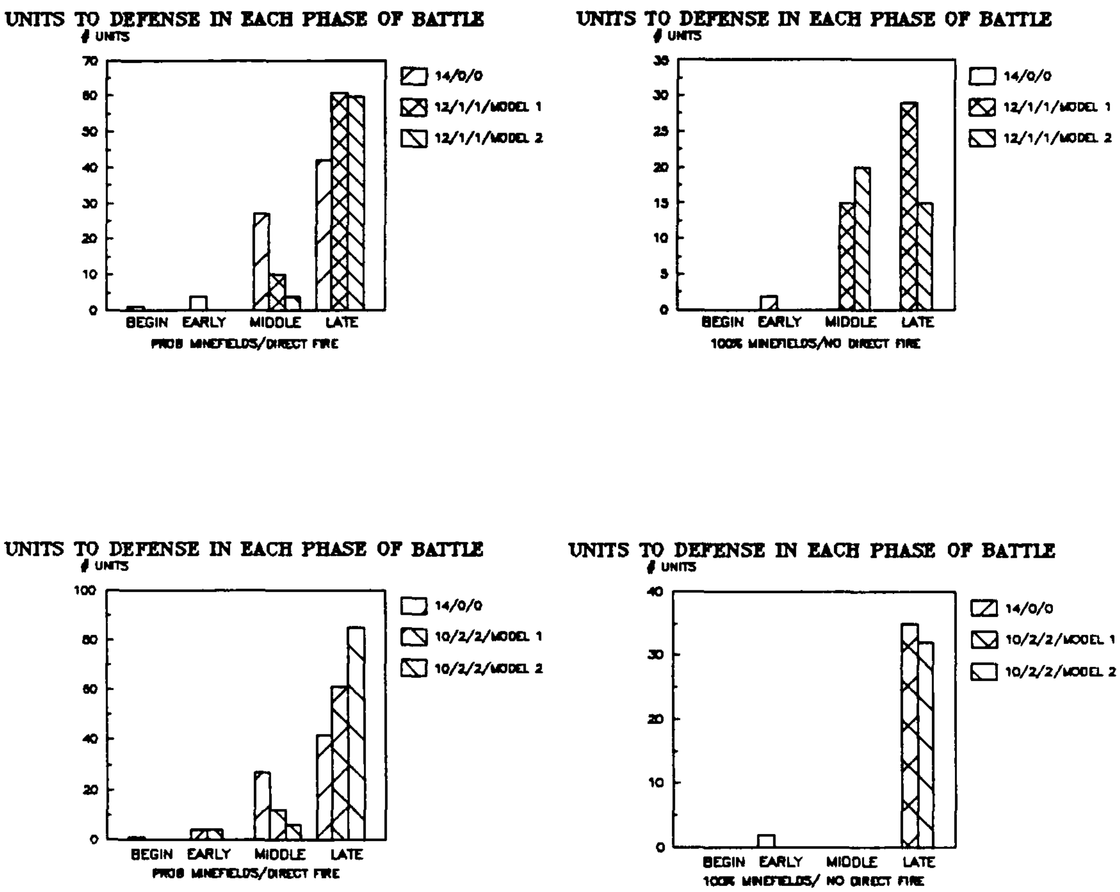
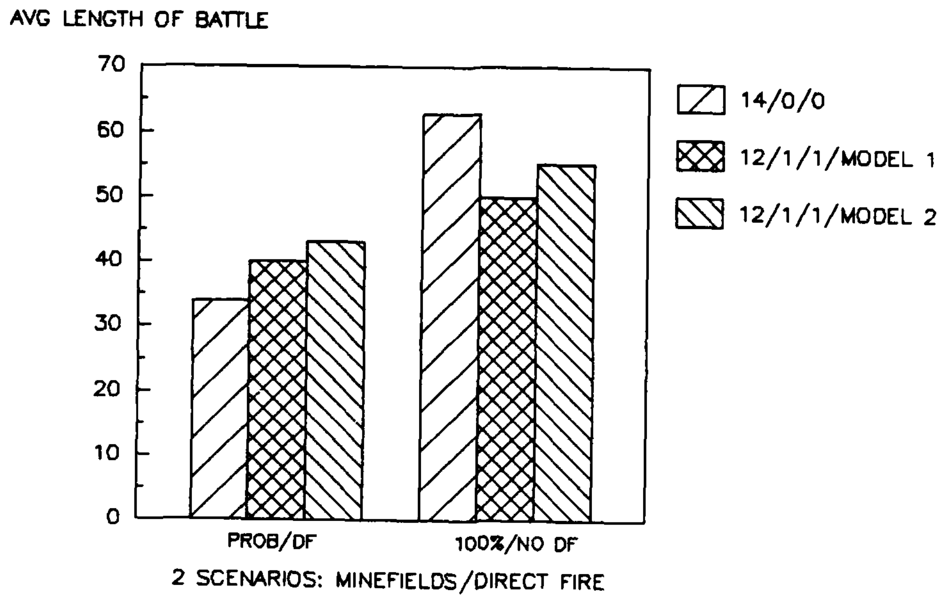


Figure 30. Model 1 versus Model 2
Measure of Effectiveness 8

MEASURE OF EFFECTIVENESS 9
MODEL 1 VERSUS MODEL 2



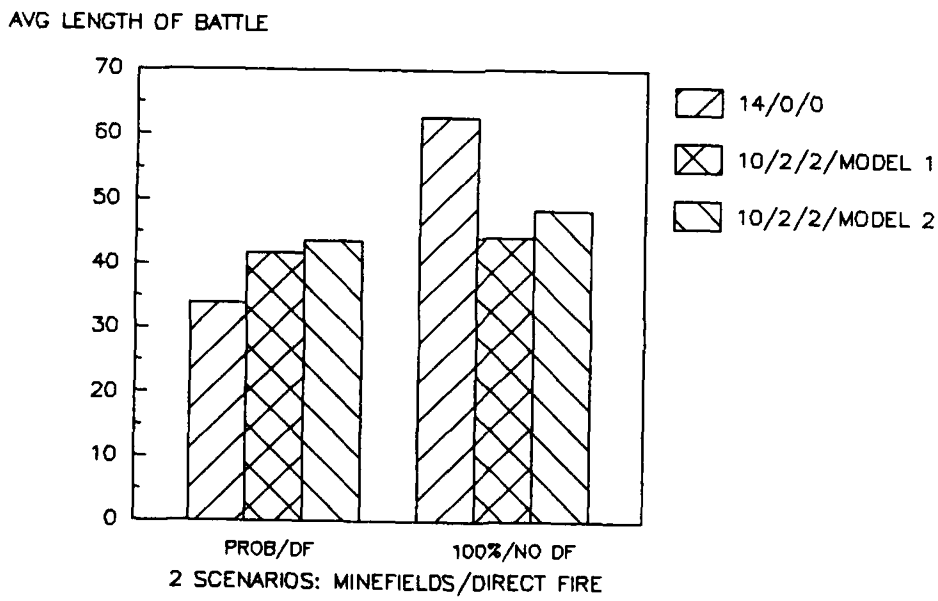
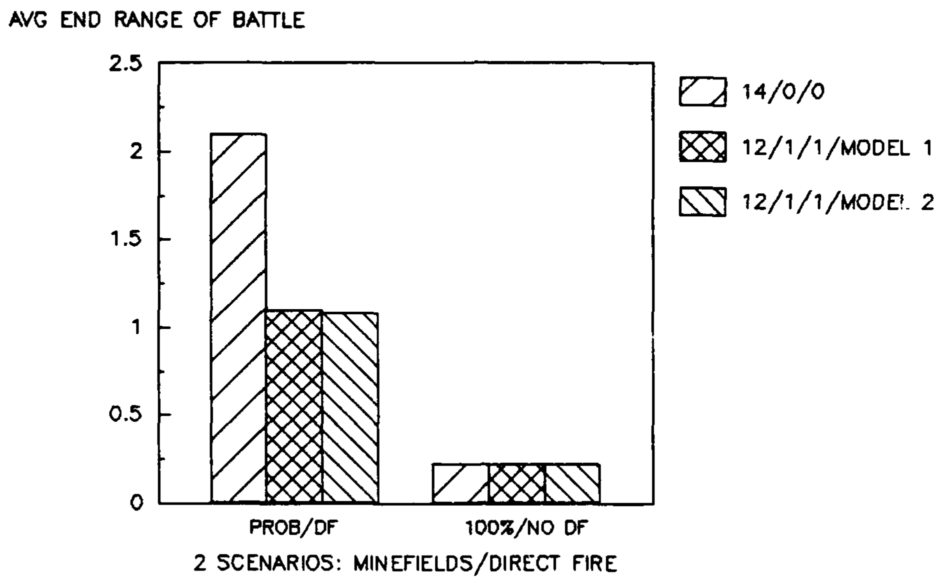


Figure 31. Model 1 versus Model 2
Measure of Effectiveness 9

MEASURE OF EFFECTIVENESS 10
MODEL 1 VERSUS MODEL 2



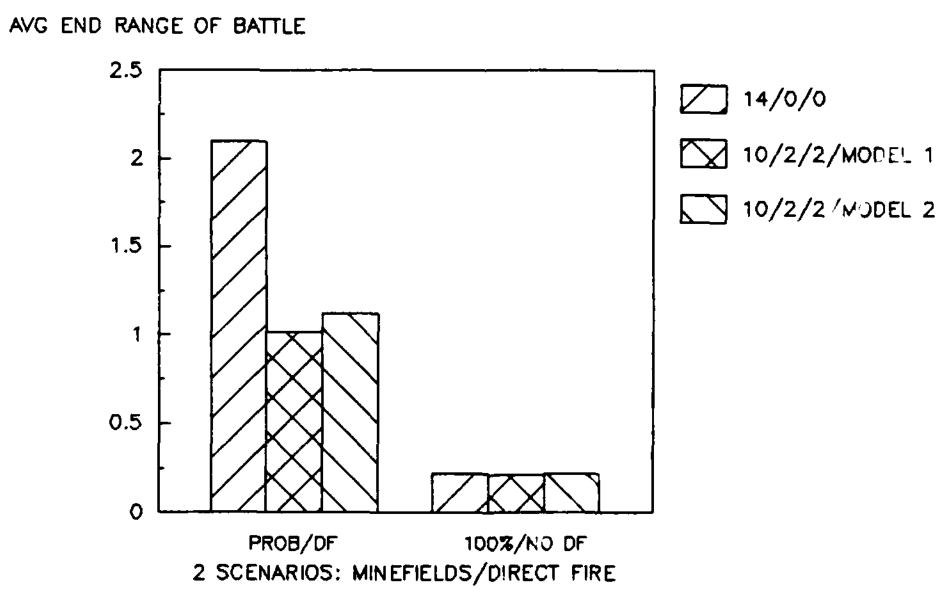
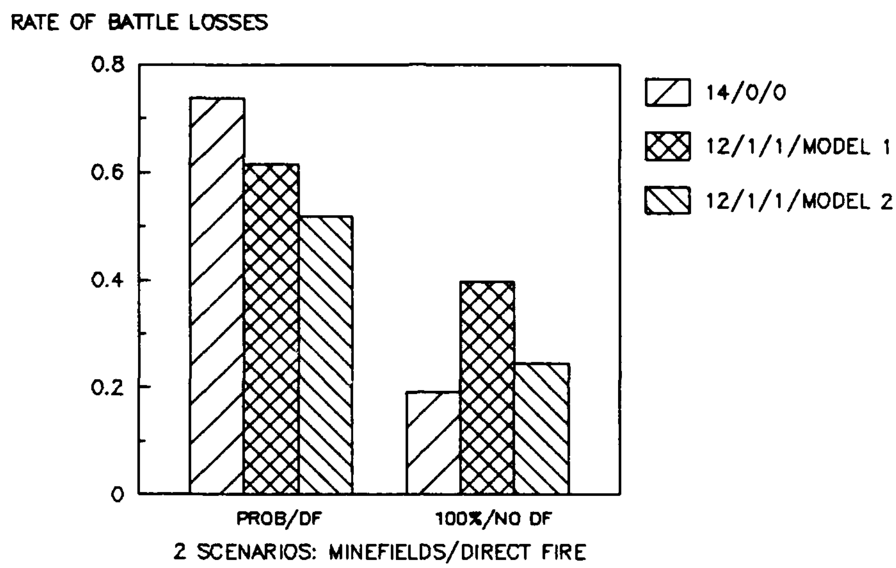


Figure 32. Model 1 versus Model 2
Measure of Effectiveness 10

MEASURE OF EFFECTIVENESS 11
MODEL 1 VERSUS MODEL 2



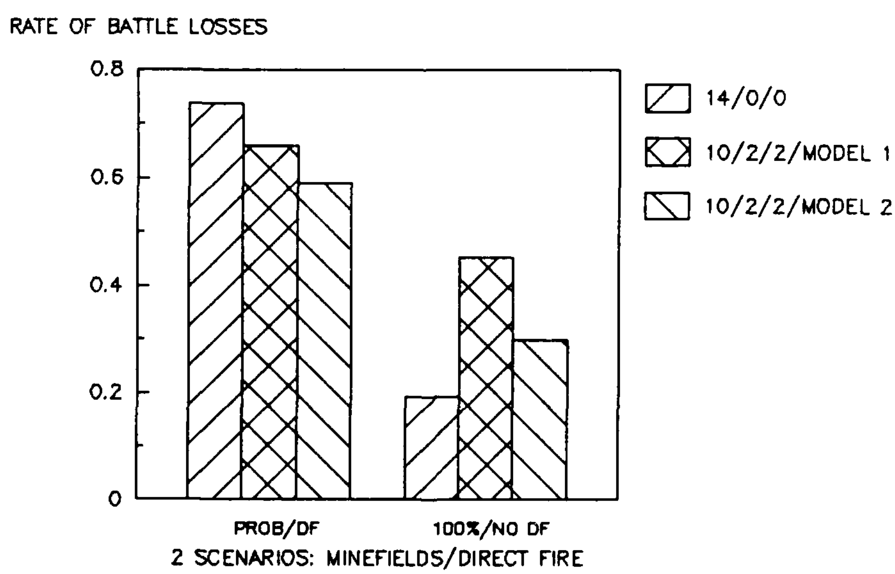


Figure 33. Model 1 versus Model 2
Measure of Effectiveness 11

V. SUMMARY, FUTURE ENHANCEMENTS, AND UTILIZATION

A. SUMMARY

The model, as developed, examines a limited number of different scenarios, tactics and equipment configurations. The combinations examined are by no means all encompassing. Continued analysis using the model as developed will provide answers to many mine/countermine questions concerning equipment and doctrine.

The model is a high resolution stochastically based simulation with a minimal amount of background routines to support the minefield breaching logic. While it will not answer all the questions concerning the basis of issue of countermine equipment, it does improve the analyst's ability to make decisions regarding the effectiveness of the mine/countermine equipment configurations.

B. FUTURE ENHANCEMENTS

The following additions or improvements to the model are recommended:

1. Addition of indirect fire to suppress both forces and allow smoke to be used to obscure the breaching sites through the minefields.

2. Development of a red movement network so a blue counterattack scenario may be examined.

3. A better method of controlling the breaching equipment during the conduct of the breach is required. At present the equipment must stay in the order input in the data file. Therefore if a unit has two mineplow tanks and a mineroller tank, and if the first mineplow clears a lane, the proofing vehicle would be a mineplow tank if it was entered

second in the file, as opposed to the mineroller tank as called for by doctrine.

4. A more accurate method of determining the destruction of a piece of breaching equipment is required. In the simulation, if one side of a mineplow or mineroller is rendered inoperable, then the entire system is considered lost. Additionally, the probability of surviving a mine detonation could be considered cumulative in nature, where the probability of surviving the first mine detonation to a breaching system may be higher than surviving the second etc.

5. The assumption of perfect knowledge concerning the extent of the minefield when it is identified does not accurately model the real world. A method of dealing with unclear or unknown boundaries of an obstacle must be developed to better simulate the actions of a unit encountering the minefield.

C. UTILIZATION

The model as it currently exists may be used to develop, examine and verify tactics. The placement of equipment within a formation, how far in the lead the mineroller should be placed and other tactics may be examined. Formations may dictate the number of breaching assets required. If the breaching equipment is in the forward platoons but not employed, they may encounter a minefield and be rendered inoperative prior to commencement of breaching operations. By changing the depths of the minefield, problems concerning the angle of attack on an obstacle may be examined.

The output generated by this model provides the appropriate information in the proper format required for more analytical models. One such model is a Semi-Markov

Renewal Process which aggregates high resolution data into various transition matrices. [Ref. 13]

Therefore, not only is the model useful as developed to investigate the issuance of countermine equipment, but may also be used in all areas concerning minefields and the tactics used to counter the obstacle.

APPENDIX A DEFINITION OF MODEL ONE VARIABLES

The variables used in Model 1 are defined below. All variables are either integer or single precision. The only double precision variable used in the model was the seed for the random number generator.

AAA	-- Speed adjustment factor to maintain movement control.
ACTIVE1,ACTIVE2	-- The first 2 elements of a unit entering a minefield; they are the candidates for detonating a mine.
ANGLE	-- Heading in radians of the arcs in the network.
ARC	-- Line connecting 2 nodes, supporting the movement of the units.
AVE	-- Avenue of approach, consisting of a series of arcs from the movement network.
BEHIND	-- Binary variable; it is 1 when AAA is greater than 1; 0 otherwise.
BLUECODE,REDCODE	-- Status code of the unit; for the blue force it may be; 0-defensive posture, 1-assault formation, 2-breaching formation. For the red force, if it equals 0 the unit is not combat effective.
BLUEDETECT1, REDDETECT1,2	-- The numerical identifier of the elements on the firer's detection list.
BLUENEGAGE,REDENGAGE	-- Number of elements in one force detecting or engaging an element of the opposing force. Up to four blue elements may detect/engage a single red element while only two red elements may detect a single blue element.

BLUEPDET,REDPDET	-- Probability of detecting an opposing element using the detection rate, DETRATE.
BLUERMAX,RMAX	-- Maximum effective engagement ranges for the weapons systems; user input variables.
BLUESTATUS,REDSTATUS	-- Indicates the current status of an element, the status may be: 0-element is dead, 1-element is in the detecting phase, 2-element is in the firing phase.
BLUEX1POS,BLUEY1POS	-- Actual x,y coordinates of elements in each blue unit.
BLUEXOFF_,BLUEYOFF_	-- These values represent the offset distances in the x direction and y direction from the control vehicle. There is an x distance and a y distance for each of the three formations and are user input.
BLUEXPOS,BLUEYPOS	-- Actual x,y coordinates of the control vehicle in each of the blue units.
BPHITS,BPKILL	-- The probabilities associated with hitting and killing a red target using the range to delineate the probabilities.
BULL1,BULL2	-- Status indicators to determine if a unit is bulling through a minefield.
BVEHORDER	-- An array which stores the order of the units as read from the data file.
BYPASS1,BYPASS2	-- Status indicators to determine if a unit is bypassing a minefield.
CLOCK	-- Keeps track of the time of battle.
CLOSE	-- Binary variable used in conjunction with the AAA variable.

CODEO	-- Records the time a unit goes to a defensive posture.
CV	-- Crossing velocity; used in the detection module and represents the component of movement perpendicular to the target-observer line-of-sight.
DELX,DELY	-- Represents the distance in the x and y directions the control vehicle moves during a single time step.
DENSMINE1,DENSMINE2	-- Represents the densities of the near and far minefields; it is user input.
DEPMINE1,DEPMINE2	-- The depth of a minefield, based on the maximum and minimum depth parameters and a Monte Carlo draw.
DETRATE	-- The rate at which a detection can occur, used in calculation of the probability of detecting a vehicle.
DFKILL	-- Counter to keep track of the number of direct fire kills per repetition.
DFTYPE	-- Counter to keep track of the total number of direct fire kills by type over each repetition.
DIST	-- Actual length of each arc; user input as part of the network.
DISTANCE	-- Cumulative distance traveled along an arc.
DISTDET1,DISTDET2	-- Represents the distance to next detonation of a mine; used in both the initial entry to a minefield routine and during breaching operations.
ENTRY1,ENTRY2	-- Variables used to determine when a minefield has been entered.

EQUIP	-- Used in the Unit Status subroutine to aid in tabulating types of equipment in the unit.
HEAD	-- Head of an arc; a node number.
HEIGHT,RHEIGHT	-- Represents the actual heights of the equipment in the various units; user input.
LAG	-- User input value representing the maximum range deviation in the assaulting units.
LOC	-- Represents the current arc location of the unit.
MAXDEPTH1,MAXDEPTH2	-- User input; the maximum depths of minefields 1 and 2.
MINDEPTH1,MINDEPTH2	-- User input; the minimum depths of minefields 1 and 2.
MINE1,MINE2	-- User input; the arcs on which the minefields located.
MINEDET1,MINEDET2	-- User input; the probabilities associated with detecting the presence of a minefield.
MINEKILL	-- Counter to keep track of the number of kills due to mine detonations per repetition.
MINEPK	-- User input; the probability that a mine kills a tank given detonation.
MOVE	-- Cumulative distance indicator that keeps track of the distance a unit has moved through a minefield.
NARC	-- Number of arcs in the network.
NNODE	-- Number of nodes in the network.
NODE	-- Specific number of a node.
NUMBLUE,NUMRED	-- Number of blue elements per unit and the total number of red elements.

NUNIT	-- Number of blue units in the simulation.
PDETONAT4	-- User input; the probability of a mine detonating when cleared by a breaching device.
PCLEAR4,PCLEAR5	-- Probabilities of a breaching device clearing a mine given an encounter.
PSURVIV4,PSURVIV5	-- Probabilities of surviving an encounter with a mine.
PDETTNK4,PDETTNK5	-- The cumulative probability of clearing a mine, either by the breaching device or detonation by the carrier.
PMINE1,PMINE2	-- User input; the probabilities of a minefield being emplaced, also interpreted the probabilities of encountering a minefield given it is emplaced.
PRCNTEFFB,PRCNTEFFR	-- Used in the Unit Status subroutine, they keep track of the combat effectiveness of the units.
RANGE	-- Range is calculated throughout the simulation and is the distance from blue element to red element.
REDX,REDY	-- Represents the center of mass of the red position in the x,y plane.
REDXPOS,REDYPOS	-- User input; the locations of the red elements in the x,y plane.
RNGADJ	-- The calculated adjusted range to a target based on the range adjustment factors input into the detection model.
RNGAPP	-- The calculated apparent range to a target based on the percent of the target that is visible to the observer.

RNGDET1,RNGDET2	-- Ranges to the detected elements in the blue force; used to determine which vehicles go on the red elements' detected list.
RNGMAX,RNGMIN	-- At any given time step the blue units are in the interval [RNGMIN,RNGMAX] which is the distance from the enemy.
RPLOOK	-- User input; the probability that a red element is looking in the direction of the target.
SPEED	-- User input; the maximum speed each vehicle type is able to maintain on each arc based on terrain characteristics.
STATMIN1,STATMIN2	-- Binary variables; used to indicate the status of minefields.
TAU	-- Terrain complexity code ranging from 1 to 7; used in the probability of detection equation.
RPHITM,RPKILL	-- The probabilities associated with hitting and killing a blue target using range to delineate the probabilities.
PHIT,PKILL	-- The actual values calculated from the table look-up which are then compared to a random number draw.
RRAF,RAF	-- Range adjustment factors for the red and blue forces; used to calculated adjusted ranges for each target.
TDFKILL,TMINEKILL	-- Total number of kills over the 50 repetitions due to direct fire and mines, respectively.

TPLOWKILL,TROLLKILL -- Total number of mineplows and minerollers killed over the 50 repetitions due to mine detonations. Thess represent only the breaching device being destroyed, not the carrier.

TPLOWBRCHKILL, TROLLBRCHKILL -- Total number of mineplow carriers and mineroller carriers killed by mine detonations over the 50 repetitions while conducting breaching operations.

TKILL -- Total number of kills due to all causes over a single repetition.

TTKILL -- A tabulating variable used in the output file, representing the total number of kills of all types over fifty repetitions.

UNIT -- Counter to track which is the current unit; the simulation will allow up to 10 units.

UNITSPD -- The speed the unit moves based on formation, location and equipment.

VEHTYPE,RVEHTYP -- These variables are coded for the type of vehicles in the units. The blue force has five types as discussed in Chapter 3 while the red force has two vehicle types; a BMP and a tank.

WIDTH -- The width is the effective width of the vehicle entering a minefield and is used in the calculation of the distance to a mine encounter.

XNODE,YNODE -- These values represent the X and Y grid coordinates of the nodes in the network.

XOFFPLT,YOFFPLT -- The x,y offsets used in the OFFSET subroutine to calculate the actual x,y coordinates.

APPENDIX B

COMPUTER PROGRAM LISTING

```
* SIMULATION MAIN PROGRAM
*****************  VARIABLE DECLARATION  ******************
      INTEGER   TAIL,HEAD,NODE,NNODE,ARC,BLUECODE,REDCODE,DEF
      INTEGER   AVE,START,NUNIT,LOC,NUMRED,REDENGAGE,STATMIN1,ENTRY1
      INTEGER   NARC,ISTART,LAST,UNIT,RED,REDSTATUS,VEHTYPE,RVEHTYP
      INTEGER   BLUESTATUS,ELEMENT,POSITION,NUMBLUE,CLOSE,BEHIND,REP
      INTEGER   REDDETECT1,REDDETECT2,BLUEENGAGE,BLUEDETECT1,MINE1
      INTEGER   BVEHORDER,BULL1,BULL2,BYPASS1,MINE2,STATMIN2,ENTRY2
      INTEGER   BYPASS2,MINEKILL,DFKILL,ROLLKILL,PLOWKILL,ROLLBRCHKILL
      INTEGER   TMINEKILL,TDFKILL,TROLLKILL,TPLOWKILL,TROLLBRCHKILL
      INTEGER   PLOWBRCHKILL,TPLOWBRCHKILL,TKILL,TTKILL,DFTYPE,MTYPE
      REAL  WIDTH,DIST,ANGLE,XNODE,YNODE,CLOCK,SP,BLUEXOFF1,BLUEYOFF1
      REAL  BLUEXOFF2,BLUEYOFF2,BLUEX1POS,BLUEY1POS,REDXPOS,REDYPOS
      REAL  BLUEXOFF0,BLUEYOFF0,MINDEPTH1,MAXDEPTH1,RNG,CODE0
      REAL  DELX,DELY,TRAVEL,SPEED,DISTANCE,CV,UNITSPD,RHEIGHT,RRAF
      REAL  RPLOOK,REDX,REDY,BLUEXPOS,BLUEYPOS,LAG,AAA,RMAX
      REAL  DENSMINE1,PMINE1,DISTDET1,DEPMINE1,MINDEPTH2,MAXDEPTH2
      REAL  BLUERMAX,DENSMINE2,PMINE2,DISTDET2,DEPMINE2
      REAL  RPHITS,RPHITM,RPKILL,BPHITS,BPKILL
      REAL*8  DSEED
      DIMENSION TAIL(150),HEAD(150),TIME(150),AVE(10,30),BULL1(10)
      DIMENSION FLOW(100),DIST(100),WIDTH(100),ISTART(10),BYPASS1(10)
      DIMENSION ARC(100),SP(100),ANGLE(100),DISTANCE(10),CV(10)
      DIMENSION NODE(150),XNODE(150),YNODE(150),BLUEDETECT1(10,20)
      DIMENSION BLUEXPOS(20),BLUEYPOS(20),RHEIGHT(30),RRAF(30),RMAX(30)
      DIMENSION SPEED(10,80),BLUEYOFF1(20),BLUEXOFF1(20),LOC(10)
      DIMENSION BLUEXOFF2(20),BLUEYOFF2(20),RVEHTYP(30),BLUECODE(10)
      DIMENSION BLUEXOFF0(20),BLUEYOFF0(20),STATMIN1(10),MINE1(10)
      DIMENSION BLUEX1POS(10,20),BLUEY1POS(10,20),BLUESTATUS(10,20)
      DIMENSION REDXPOS(50),REDYPOS(50),RPLOOK(10,50),UNITSPD(10)
      DIMENSION RED(50),REDSTATUS(30),VEHTYPE(10,20),REDENGAGE(100)
      DIMENSION REDDETECT1(30),REDDETECT2(30),BLUEENGAGE(30),MINE2(10)
      DIMENSION PMINE2(10),DISTDET2(10,100),DEPMINE2(10),ENTRY2(10)
      DIMENSION PMINE1(10),DISTDET1(10,100),DEPMINE1(10),ENTRY1(10)
      DIMENSION RPHITS(10),RPHITM(10),RPKILL(10),BPHITS(10),BPKILL(10)
      DIMENSION BVEHORDER(10,20),RNG(20),STATMIN2(10),BYPASS2(10)
      DIMENSION BULL2(10),MINEKILL(100),DFKILL(100),ROLLKILL(100)
      DIMENSION PLOWKILL(100),ROLLBRCHKILL(100),PLOWBRCHKILL(100)
      DIMENSION BLUERMAX(10,20),DFTYPE(20),MTYPE(20),CODE0(10),DEF(10)
*
         OPEN (UNIT = 54 , FILE = 'SIMUL')
         OPEN (UNIT = 44 , FILE = 'RESULTS')
         OPEN (UNIT = 34 , FILE = 'OUTPUT')
         OPEN (UNIT = 24 , FILE = 'MINETIME')
         OPEN (UNIT = 23 , FILE = 'TIMEMINE')

********************  SET INITIAL OPTIONS  ***********************

*
*             SET START NODE
         START = 1
*             SET LAST NODE
         LAST  = 29
*             TOTAL NUMBER OF ARCS IN THE SECTOR
         NARC  = 31
*             TOTAL NUMBER OF NODES IN THE SECTOR
         NNODE  = 29
*             NUMBER OF AVENUES OF APPROACH
```

```
            NUNIT = 4
*                 NUMBER OF RED ELEMENTS
            NUMRED = 13
*                 NUMBER OF BLUE ELEMENTS IN EACH UNIT
             NUMBLUE=14

*   SET INITIAL CONDITIONS
*SET RANDOM NUMBER SEED
                DSEED=1029395.D0


*SET TERRAIN CODE
                TAU = 3.5


*
************* READ DATA FROM DATA FILES ***********************
*
        READ(1,100) (ARC(I),TAIL(I),HEAD(I),DIST(I),ANGLE(I),I=1,NARC)
100     FORMAT(2X,I3,3X,I2,3X,I2,4X,F4.2,3X,F5.3)
        READ(2.200) (NODE(I),XNODE(I),YNODE(I),I=1,NNODE)
200     FORMAT(2X,I3,2X,F5.0,1X,F5.0)

        READ(3,300)((AVE(K,I),K=1,4),I=1,13)
300     FORMAT(2X,I3,2X,I3,2X,I3,2X,I3)

        READ(4,400)((SPEED(K,I),K=1,5),I=1,NARC)
400     FORMAT(2X,5F4.0)

        READ(9,500) (BLUEXOFF0(I),BLUEYOFF0(I),I=1,NUMBLUE)
        READ(10,500) (BLUEXOFF1(I),BLUEYOFF1(I),I=1,NUMBLUE)
        READ(11,500) (BLUEXOFF2(I),BLUEYOFF2(I),I=1,NUMBLUE)
500     FORMAT(2X,F5.2,2X,F5.2)

        READ(17,550) (BPHITS(I),BPKILL(I),I=1,8)
550     FORMAT(2X,F4.2,2X,F4.2)

        READ(12,600) (RED(I),REDXPOS(I),REDYPOS(I),I=1,NUMRED)
600     FORMAT (2X,I2,2X,F5.1,2X,F5.1)

        READ(13,700) ((RPLOOK(K,I),K=1,NUNIT),I=1,NUMRED)
700     FORMAT(2X,4F6.2)

        READ(14,800) ((BVEHORDER(K,I),K=1,NUNIT),I=1,NUMBLUE)
800     FORMAT(2X,I1,2X,I1,2X,I1,2X,I1)

        READ(15,900) (RVEHTYP(I),RHEIGHT(I),RRAF(I),RMAX(I),I=1,NUMRED)
900     FORMAT(2X,I1,2X,F3.1,2X,F3.1,2X,F3.1)

        READ(16,950) (RPHITS(I),RPHITM(I),RPKILL(I),I=1,9)
950     FORMAT(2X,F4.2,2X,F4.2,2X,F4.2)


            TROLLBRCHKILL=0
            TPLOWBRCHKILL=0
            TMINEKILL=0
            TDFKILL=0
            TROLLKILL=0
            TPLOWKILL=0
```

```
      DO 181 REP=1,50
        WRITE(54,928) REP
928     FORMAT('**********  REPITITION NUMBER ',I3' **********')
**********************************************************************
*     START SIMULATION
          RNGMIN = 20.0
          MINEKILL(REP)=0
          DFKILL(REP)=0
          DFTYPE(1)=0
          DFTYPE(2)=0
          DFTYPE(3)=0
          DFTYPE(4)=0
          DFTYPE(5)=0
          MTYPE(1)=0
          MTYPE(2)=0
          MTYPE(3)=0
          PLOWKILL(REP)=0
          ROLLKILL(REP)=0
          ROLLBRCHKILL(REP)=0
          PLOWBRCHKILL(REP)=0
        CLOCK = 0.0
        REDX=XNODE(26)
        REDY=YNODE(26)
        REDCODE = 1
*MINEFIELD NUMBER 1 LOCATIONS
        MINE1(1)=10
        MINE1(2)=9
        MINE1(3)=17
        MINE1(4)=22
        MINDEPTH1=150
        MAXDEPTH1=300
        DENSMINE1=.003
        PMINE1(1)=0.70
        PMINE1(2)=0.70
        PMINE1(3)=0.70
        PMINE1(4)=0.70
*MINEFIELD NUMBER 2 LOCATIONS
        MINE2(1)=13
        MINE2(2)=12
        MINE2(3)=26
        MINE2(4)=24
        MINDEPTH2=200
        MAXDEPTH2=300
        DENSMINE2=.02
        PMINE2(1)=0.90
        PMINE2(2)=0.90
        PMINE2(3)=0.90
        PMINE2(4)=0.90
      DO 40 UNIT=1,NUNIT
         BLUECODE(UNIT) = 1
```

```
              DEF(UNIT)=0
              CODE0(UNIT)=0
              ISTART(UNIT)=1
              LOC(UNIT)=AVE(UNIT,1)
              BLUEXPOS(UNIT) = XNODE(TAIL(LOC(UNIT)))
              BLUEYPOS(UNIT) = YNODE(TAIL(LOC(UNIT)))
              DISTANCE(UNIT)=0.0
              UNITSPD(UNIT)=0.0
              STATMIN1(UNIT)=0
              STATMIN2(UNIT)=0
              ENTRY1(UNIT)=0
              ENTRY2(UNIT)=0
              BULL1(UNIT)=0
              BYPASS1(UNIT)=0
              BULL2(UNIT)=0
              BYPASS2(UNIT)=0
           DO 47  POSITION=1,NUMBLUE
              VEHTYPE(UNIT,POSITION)=BVEHORDER(UNIT,POSITION)
              BLUESTATUS(UNIT,POSITION)=1
              REDENGAGE((NUMBLUE*(UNIT-1))+POSITION)=0

*************BLUE MAX ENGAGEMENT RANGE***************
              BLUERMAX(UNIT,POSITION)= 3.0

47         CONTINUE
40         CONTINUE

           DO 13 ELEMENT=1,NUMRED

              REDSTATUS(ELEMENT)=1
              BLUEENGAGE(ELEMENT)=0
13        CONTINUE

********     SIMULATION START    ****************


                CALL MINESETUP (UNIT,NUNIT,DSEED,PMINE1,
     *                STATMIN1,MINDEPTH1,MAXDEPTH1,DEPMINE1,DENSMINE1,
     *                DISTDET1,PMINE2,STATMIN2,MINDEPTH2,MAXDEPTH2,
     *                DEPMINE2,DENSMINE2,DISTDET2)

         DO 20 J=1,200
                CLOCK=CLOCK+.5


             CALL UNITSTATUS(BLUECODE,REDCODE,UNIT,NUNIT,POSITION,NUMBLUE,
     *               BLUESTATUS,REDSTATUS,NUMRED,ELEMENT,VEHTYPE,CLOCK,REP,
     *               RNGMIN)

* CHECKS TO DETERMINE IF BATTLE TERMINATION CRITERIA HAS BEEN MET

                  IF (REDCODE .EQ. 0) GO TO 179
             CALL LOCATION ( LAG,UNIT,NUNIT,BLUEXPOS,BLUEYPOS,RNG,
     *                    RNGMIN,REDX,REDY,AAA,CLOSE,BEHIND,BLUECODE)

                IF(RNGMIN .LT. .250) THEN
             CALL UNITSTATUS(BLUECODE,REDCODE,UNIT,NUNIT,POSITION,NUMBLUE,
     *               BLUESTATUS,REDSTATUS;NUMRED,ELEMENT,VEHTYPE,CLOCK,REP,
     *               RNGMIN)
                 END IF
```

```
              IF(RNGMIN .LT. .250) GO TO 179

* ENTER MOVEMENT ROUTINE
          DO 30 UNIT=1,NUNIT

*CHECK TO SEE IF UNIT HAS ENTERED MINEFIELD; 30 SECOND MOVEMENT DELAY
               IF(ENTRY1(UNIT) .EQ. 1) THEN
                    ENTRY1(UNIT)=2
                    GO TO 30
               END IF
               IF(ENTRY2(UNIT) .EQ. 1) THEN
                    ENTRY2(UNIT)=2
                    GO TO 30
               END IF

           CALL MOV1 (LOC,TAIL,XNODE,YNODE,SPEED,TRAVEL,ANGLE,AVE,DIST,
     *           NODE,ISTART,DISTANCE,BLUEXPOS,BLUEYPOS,CLOCK,UNIT,
     *           BLUEXOFF1,BLUEYOFF1,BLUEXOFF2,BLUEYOFF2,ENTRY1,
     *           BLUEX1POS,BLUEY1POS,UNITSPD,NUMBLUE,VEHTYPE,AAA,
     *           CLOSE,BEHIND,BLUECODE,BLUEXOFF0,BLUEYOFF0,DEPMINE1,
     *           MINE1,STATMIN1,DSEED,BLUESTATUS,DISTDET1,REDX,REDY,
     *           BLUEDETECT1,RNG,BULL1,BYPASS1,ENTRY2,DEPMINE2,MINE2,
     *           STATMIN2,DISTDET2,BULL2,BYPASS2,MINEKILL,ROLLKILL,
     *           PLOWKILL,ROLLBRCHKILL,PLOWBRCHKILL,REP,MTYPE)
30        CONTINUE

* RED DETECT/FIRE ROUTINE ENTERED
          DO 43 ELEMENT=1,NUMRED
              IF (REDSTATUS(ELEMENT) .EQ. 0) THEN
                     GO TO 43
              ELSE IF (REDSTATUS(ELEMENT) .EQ. 2) THEN

         CALL REDFIRE(REDSTATUS,ELEMENT,REDENGAGE,BLUESTATUS,UNIT,
     *          POSITION,NUMBLUE,REDXPOS,REDYPOS,NUNIT,VEHTYPE,
     *          REDDETECT1,REDDETECT2,BLUEX1POS,BLUEY1POS,DSEED,CLOCK,
     *          RVEHTYP,RPHITS,RPHITM,RPKILL,DFKILL,REP,DFTYPE)
                GO TO 43
               END IF

             CALL REDDETECT (REDXPOS,REDYPOS,BLUEXPOS,BLUEYPOS,
     *            BLUEX1POS,BLUEY1POS,NUNIT,REDENGAGE,BLUESTATUS,
     *            ANGLE,UNIT,UNITSPD,CLOCK,LOC,CV,NUMRED,NUMBLUE,
     *            REDX,REDY,RED,RPLOOK,REDSTATUS,DSEED,VEHTYPE,
     *            REDDETECT1,REDDETECT2,ELEMENT,POSITION,TAU,RVEHTYP,
     *            BLUECODE,RMAX)

43       CONTINUE

* BLUE DETECT/FIRE ROUTINE ENTERED
          DO 63 UNIT=1,NUNIT
             DO 69 POSITION=1,NUMBLUE
              IF (BLUESTATUS(UNIT,POSITION) .EQ. 0) THEN
                     GO TO 69
              ELSE IF (VEHTYPE(UNIT,POSITION) .EQ. 4 .OR.
     *                  VEHTYPE(UNIT,POSITION) .EQ. 5) THEN
                     GO TO 69
              ELSE IF (BLUESTATUS(UNIT,POSITION) .EQ. 2) THEN
```

```
          CALL BLUEFIRE(REDSTATUS,ELEMENT,BLUEENGAGE,BLUESTATUS,UNIT,
     *              POSITION,REDXPOS,REDYPOS,RVEHTYP,
     *              BLUEDETECT1,BLUEX1POS,BLUEY1POS,DSEED,
     *              CLOCK,BPHITS,BPKILL)
                GO TO 69
              END IF

            CALL BLUEDETECT (REDXPOS,REDYPOS,BLUEX1POS,BLUEY1POS,
     *          BLUEENGAGE,BLUESTATUS,REDSTATUS,DSEED,UNIT,CLOCK,NUMRED,
     *          BLUEDETECT1,ELEMENT,POSITION,TAU,RVEHTYP,RHEIGHT,RRAF,
     *          BLUERMAX)

 69         CONTINUE
 63         CONTINUE

*CHECK TO SEE TIME UNIT GOES TO DEFENSIVE POSTURE
              DO 159 UNIT=1,NUNIT
                IF (BLUECODE(UNIT) .EQ. 0 .AND. DEF(UNIT) .EQ. 0) THEN
                        CODE0(UNIT) = CLOCK
                        DEF(UNIT) = 1
                END IF
 159          CONTINUE
 20       CONTINUE

* RUNNING TOTAL OF LOSSES
 179                TDFKILL=TDFKILL+DFKILL(REP)
                    TMINEKILL=TMINEKILL+MINEKILL(REP)
                    TROLLKILL=TROLLKILL+ROLLKILL(REP)
                    TPLOWKILL=TPLOWKILL+PLOWKILL(REP)
                    TROLLBRCHKILL=TROLLBRCHKILL+ROLLBRCHKILL(REP)
                    TPLOWBRCHKILL=TPLOWBRCHKILL+PLOWBRCHKILL(REP)
                    TKILL=DFKILL(REP)+MINEKILL(REP)+ROLLBRCHKILL(REP)+
     *                                   PLOWBRCHKILL(REP)

            WRITE(44,338) DFKILL(REP),DFTYPE(1),(DFTYPE(2)+DFTYPE(4)),
     *          (DFTYPE(3)+DFTYPE(5)),ROLLKILL(REP),PLOWKILL(REP),
     *          MINEKILL(REP),MTYPE(1),MTYPE(2),MTYPE(3),
     *          PLOWBRCHKILL(REP),ROLLBRCHKILL(REP),TKILL,CLOCK,RNGMIN
 338        FORMAT(I2,'/',I2,'/',I2,'/',I2,1X,I2,4X,I2,3X,I2,'/',
     *                I2,'/',I2,'/',I2,4X,I2,7X,I2,6X,I3,4X,F4.1,2X,F6.3)
            WRITE(34,377) DFKILL(REP),DFTYPE(1),(DFTYPE(2)+DFTYPE(4)),
     *          (DFTYPE(3)+DFTYPE(5)),ROLLKILL(REP),PLOWKILL(REP),
     *          MINEKILL(REP),MTYPE(1),MTYPE(2),MTYPE(3),
     *          PLOWBRCHKILL(REP),ROLLBRCHKILL(REP),TKILL,CLOCK,RNGMIN
 377        FORMAT(2X,13I4,2X,F4.1,2X,F5.3)
            WRITE(24,577) STATMIN1(1),STATMIN2(1),CODE0(1),
     *                    STATMIN1(2),STATMIN2(2),CODE0(2),
     *                    STATMIN1(3),STATMIN2(3),CODE0(3),
     *                    STATMIN1(4),STATMIN2(4),CODE0(4),CLOCK
            WRITE(23,577) STATMIN1(1),STATMIN2(1),CODE0(1),
     *                    STATMIN1(2),STATMIN2(2),CODE0(2),
     *                    STATMIN1(3),STATMIN2(3),CODE0(3),
     *                    STATMIN1(4),STATMIN2(4),CODE0(4),CLOCK
 577        FORMAT(2X,2I4,F5.1,2X,2I4,F5.1,2X,2I4,F5.1,2X,2I4,F5.1,2X,F5.1)


 181      CONTINUE
```

```
      TTKILL=TDFKILL+TMINEKILL+TROLLBRCHKILL+TPLOWBRCHKILL

      WRITE(44,333)
 333  FORMAT('TOTAL NUMBER OF KILLS BY CATEGORY')
      WRITE(44,334)
 334  FORMAT('DIRECTFIRE    ROLL    PLOW    MINE    PLOWCARRIER ',
     *          '    ROLLCARRIER    TOTALKILLS')
      WRITE(44,335) TDFKILL,TROLLKILL,TPLOWKILL,TMINEKILL,
     *                           TPLOWBRCHKILL,TROLLBRCHKILL,TTKILL
 335  FORMAT(5X,I3,4X,I3,3X,I3,3X,I3,7X,I3,11X,I3,11X,I3)


      STOP
      END
**************************************************************
```

```
******************  MINESETUP  ************************************

      SUBROUTINE MINESETUP (UNIT,NUNIT,DSEED,PMINE1,
     *              STATMIN1,MINDEPTH1,MAXDEPTH1,DEPMINE1,DENSMINE1,
     *              DISTDET1,PMINE2,STATMIN2,MINDEPTH2,MAXDEPTH2,
     *              DEPMINE2,DENSMINE2,DISTDET2)
       INTEGER  UNIT,NUNIT,STATMIN1,STATMIN2,PACE
       REAL  RNDMINE,PMINE1,MINDEPTH1,MAXDEPTH1,DEPMINE1,DENSMINE1
       REAL  PMINE2,MINDEPTH2,MAXDEPTH2,DEPMINE2,DENSMINE2
       REAL  DISTDET1,DISTDET2,WIDTH
       REAL*8  DSEED
       DIMENSION  RNDMINE(100),PMINE1(10),STATMIN1(10),DISTDET1(10,100)
       DIMENSION  PMINE2(10),STATMIN2(10),DISTDET2(10,100)
       DIMENSION  DEPMINE1(10),DEPMINE2(10)

* EFFECTIVE WIDTH OF M1
       WIDTH=3.5


             DO 31 UNIT=1,NUNIT
                 CALL GGUBS (DSEED,90,RNDMINE)
*  DETERMINE STATUS OF MINEFIELD1
                 IF(RNDMINE(1) .LT. PMINE1(UNIT)) THEN
                       STATMIN1(UNIT)=1
*DETERMINE DEPTH OF MINEFIELD1
       DEPMINE1(UNIT)=(MINDEPTH1+((MAXDEPTH1-MINDEPTH1)
     *                                       *RNDMINE(2)))/1000
                 END IF

*SET UP ARRAY OF DISTANCES TO MINE ENCOUNTERS
                 IF (STATMIN1(UNIT) .EQ. 1) THEN
                     DO 32 PACE=1,88
      DISTDET1(UNIT,PACE)=((LOG(1-RNDMINE(PACE+2)))
     *                              /((-WIDTH*DENSMINE1)))/1000
               IF (DISTDET1(UNIT,PACE) .GT. DEPMINE1(UNIT)) THEN
                        DISTDET1(UNIT,PACE) = DEPMINE1(UNIT)/2
               END IF
 32         CONTINUE
                 END IF

          WRITE(54,967) UNIT,STATMIN1(UNIT),DEPMINE1(UNIT),RNDMINE(2)
 967      FORMAT('UNIT',I2,' STATUSMINE1 ',I3,' DEPTH OF FIELD ',F5.3,
     *                     ' RNDNUM ',F5.3)


* REPEAT ABOVE PROCEDURES FOR MINEFIELD2
                 CALL GGUBS (DSEED,90,RNDMINE)
                 IF(RNDMINE(1) .LT. PMINE2(UNIT)) THEN
                       STATMIN2(UNIT)=1
       DEPMINE2(UNIT)=(MINDEPTH2+((MAXDEPTH2-MINDEPTH2)
     *                                    *RNDMINE(2)))/1000
                 END IF
                 IF (STATMIN2(UNIT) .EQ. 1) THEN
                     DO 21 PACE=1,88
      DISTDET2(UNIT,PACE)=((LOG(1-RNDMINE(PACE+2)))
     *                              /((-WIDTH*DENSMINE2)))/1000
               IF (DISTDET2(UNIT,PACE) .GT. DEPMINE2(UNIT)) THEN
                        DISTDET2(UNIT,PACE) = DEPMINE2(UNIT)/2
               END IF
 21         CONTINUE
                 END IF

          WRITE(54,977) UNIT,STATMIN2(UNIT),DEPMINE2(UNIT),RNDMINE(2)
 977      FORMAT('UNIT',I2,' STATUSMINE2 ',I3,' DEPTH OF FIELD ',F5.3,
     *                     ' RNDNUM ',F5.3)
 31         CONTINUE

       RETURN
       END
******************************************************************
```

```
*****************  UNITSTATUS  ***********************************

          SUBROUTINE UNITSTATUS(BLUECODE,REDCODE,UNIT,NUNIT,POSITION,
     *     NUMBLUE,BLUESTATUS,REDSTATUS,NUMRED,ELEMENT,VEHTYPE,CLOCK,REP,
     *     RNGMIN)
         INTEGER BLUECODE,REDCODE,UNIT,NUNIT,POSITION,NUMBLUE,EQUIP
         INTEGER BLUESTATUS,REDSTATUS,NUMRED,ELEMENT,VEHTYPE,REP
         REAL    PRCNTEFFB,PRCNTEFFR,SURVIV,RSURVIV,CLOCK,RNGMIN
         DIMENSION SURVIV(10),BLUESTATUS(10,20),REDSTATUS(30)
         DIMENSION BLUECODE(10),VEHTYPE(10,20),EQUIP(10,10),PRCNTEFFB(10)

*D DETERMINE CURRENT STATUS OF RED AND BLUE FORCES
                RSURVIV = 0
          DO 42 UNIT=1,NUNIT
                SURVIV(UNIT) = 0
              DO 36 J=1,10
                   EQUIP(UNIT,J) = 0
36            CONTINUE
             DO 44 POSITION = 1,NUMBLUE
                IF (BLUESTATUS(UNIT,POSITION) .NE. 0) THEN
                            SURVIV(UNIT) = SURVIV(UNIT) + 1
                     IF (VEHTYPE(UNIT,POSITION) .EQ. 1) THEN
         EQUIP(UNIT,VEHTYPE(UNIT,POSITION))
     *                        = EQUIP(UNIT,VEHTYPE(UNIT,POSITION))+1
                   ELSE IF (VEHTYPE(UNIT,POSITION) .EQ. 2) THEN
         EQUIP(UNIT,VEHTYPE(UNIT,POSITION))
     *                        = EQUIP(UNIT,VEHTYPE(UNIT,POSITION))+1
                   ELSE IF (VEHTYPE(UNIT,POSITION) .EQ. 3) THEN
         EQUIP(UNIT,VEHTYPE(UNIT,POSITION))
     *                        = EQUIP(UNIT,VEHTYPE(UNIT,POSITION))+1
                   ELSE IF (VEHTYPE(UNIT,POSITION) .EQ. 4) THEN
         EQUIP(UNIT,VEHTYPE(UNIT,POSITION))
     *                        = EQUIP(UNIT,VEHTYPE(UNIT,POSITION))+1
                   ELSE IF (VEHTYPE(UNIT,POSITION) .EQ. 5) THEN
         EQUIP(UNIT,VEHTYPE(UNIT,POSITION))
     *                        = EQUIP(UNIT,VEHTYPE(UNIT,POSITION))+1
                   END IF
               END IF
44           CONTINUE

* CHECK TO SET IF BLUE UNIT HAS REACHED DEFENSIVE POSTURE CRITERIA
          PRCNTEFFB(UNIT) = SURVIV(UNIT)/NUMBLUE
                  IF (PRCNTEFFB(UNIT) .LT. .5) THEN
                        BLUECODE(UNIT) = 0
                  END IF

42        CONTINUE
```

```
* TABULATION OF RED STRNGTH
           DO 89 ELEMENT=1,NUMRED
               IF(REDSTATUS(ELEMENT) .NE. 0) THEN
                     RSURVIV = RSURVIV + 1
               END IF
89         CONTINUE
                   PRCNTEFFR = RSURVIV/NUMRED
               IF (PRCNTEFFR .LT. .250) THEN
                    REDCODE = 0

               END IF

* WRITE OUTPUT TO DATA FILES
           IF (CLOCK .LT. 1.0 .OR. PRCNTEFFR .LT. .250
     *                          .OR. RNGMIN .LT. .250) THEN
            DO 19 UNIT=1,NUNIT
              WRITE(54,987) UNIT,BLUECODE(UNIT),EQUIP(UNIT,1),
     *             EQUIP(UNIT,2),EQUIP(UNIT,4),EQUIP(UNIT,3),EQUIP(UNIT,5)
987             FORMAT('UNIT ',I1,' UNITCODE ',I1,' EQUIP TANK ',
     *                        I2,' MINEPLOW ' ,2I4,' MINEROLLER',2I4)
19          CONTINUE

          IF (REP .EQ. 1 .AND. CLOCK .LT. 1.0) THEN
            DO 109 UNIT=1,NUNIT
              WRITE(44,387) UNIT,BLUECODE(UNIT),EQUIP(UNIT,1),
     *             EQUIP(UNIT,2),EQUIP(UNIT,4),EQUIP(UNIT,3),EQUIP(UNIT,5)
387             FORMAT('UNIT ',I1,' UNITCODE ',I1,' EQUIP TANK ',
     *                        I2,' MINEPLOW ' ,2I4,' MINEROLLER',2I4)
109          CONTINUE

           WRITE(44,336)
336        FORMAT('NUMBER OF KILLS BY CATEGORY PER REPITITION')
           WRITE(44,337)
337        FORMAT(' DIRECTFIRE ROLL  PLOW  MINEFIELD  PLOWCARR',
     *                  ' ROLLCARR  TOTKILL CLOCK MINRNG')
           WRITE(24,537)
537        FORMAT(10X,'ACTIVE MINEFIELDS AND TIMES TO DEFENSIVE POSTURE')
           WRITE(24,538)
538        FORMAT(5X,'AVENUE 1',5X,'  AVENUE 2',5X,'  AVENUE 3',5X,
     *            '  AVENUE 4',3X,'RUN TIME')
           WRITE(24,539)
539        FORMAT('     M1  M2          M1  M2          M1  M2',
     *                       '          M1  M2')


          END IF

            WRITE(54,717) RSURVIV,REDCODE,PRCNTEFFR
717         FORMAT( 'RED UNIT #SURVIV ',F3.0,' UNITCODE ',I2,' %EFF',F5.3)
           END IF
           RETURN
            END

*******************************************************************
```

```
*******************LOCATION********************

      SUBROUTINE LOCATION (LAG,UNIT,NUNIT,BLUEXPOS,BLUEYPOS,
     *              RNG,RNGMIN,REDX,REDY,AAA,CLOSE,BEHIND,BLUECODE)
         INTEGER UNIT,NUNIT,CLOSE,BEHIND,BLUECODE
         REAL LAG,BLUEXPOS,BLUEYPOS,REDX,REDY,RNG,RNGMIN,RNGMAX,AAA
         DIMENSION  BLUEXPOS(20),BLUEYPOS(20),RNG(20),BLUECODE(10)

              LAG = 0.5
              RNGMIN = 20.0
              RNGMAX =  0.1
              CLOSE = 0
              BEHIND = 0

* CHECK TO DETERMINE IF UNITS ARE ALIGNED
               DO 57 UNIT=1,NUNIT
         RNG(UNIT)=(SQRT(((REDX-BLUEXPOS(UNIT))**2)+
     *            ((REDY-BLUEYPOS(UNIT))**2)))/10
             IF (BLUECODE(UNIT) .EQ. 0) THEN
                   GO TO 57
             END IF
            IF (RNG(UNIT) .LT. RNGMIN ) THEN
                 RNGMIN = RNG(UNIT)
                 CLOSE=UNIT
             END IF

            IF (RNG(UNIT) .GT. RNGMAX ) THEN
                 RNGMAX = RNG(UNIT)
             END IF
57       CONTINUE

* CALCULATE THE LAG FACTOR AAA
            IF((RNGMAX - RNGMIN) .GT. LAG) THEN
                  AAA = (RNGMAX-RNGMIN)/LAG
                  BEHIND = 1
             END IF
         RETURN
         END

*******************************************************************
```

```
**********          MOV1     *********************************

      SUBROUTINE MOV1 (LOC,TAIL,XNODE,YNODE,SPEED,TRAVEL,ANGLE,AVE,DIST,
     *         NODE,ISTART,DISTANCE,BLUEXPOS,BLUEYPOS,CLOCK,UNIT,
     *         BLUEXOFF1,BLUEYOFF1,BLUEXOFF2,BLUEYOFF2,ENTRY1,
     *         BLUEX1POS,BLUEY1POS,UNITSPD,NUMBLUE,VEHTYPE,AAA,
     *         CLOSE,BEHIND,BLUECODE,BLUEXOFF0,BLUEYOFF0,DEPMINE1,
     *         MINE1,STATMIN1,DSEED,BLUESTATUS,DISTDET1,REDX,REDY,
     *         BLUEDETECT1,RNG,BULL1,BYPASS1,ENTRY2,DEPMINE2,MINE2,
     *         STATMIN2,DISTDET2,BULL2,BYPASS2,MINEKILL,ROLLKILL,
     *         PLOWKILL,ROLLBRCHKILL,PLOWBRCHKILL,REP,MTYPE)
       INTEGER  TAIL,NODE,LOC,ISTART,UNIT,CLOSE,BEHIND,ENTRY1,MINE1
       INTEGER  NNODE,AVE,VEHTYPE,NUMBLUE,BLUECODE,STATMIN1,BLUESTATUS
       INTEGER  ACTIVE1,ACTIVE2,CLEAR,PSN,BLUEDETECT1,BULL1,BYPASS1
       INTEGER  ENTRY2,MINE2,STATMIN2,BULL2,BYPASS2,MINEKILL,ROLLKILL
       INTEGER  TEMPTYPE,TEMPSTATUS,TEMPDETECT,PLOWKILL,PLOWBRCHKILL,REP
       INTEGER  ROLLBRCHKILL,MTYPE
       REAL     DIST,SPEED,DISTANCE,BLUEXPOS,BLUEYPOS,MINEDET,REDX
       REAL     BLUEXOFF1,BLUYOFF1,BLUEXOFF2,BLUEYOFF2,DISTDET1,REDY
       REAL     BLUEX1POS,BLUEY1POS,BLUEXOFF0,BLUEYOFF0,WIDTH,STEPMINE1
       REAL     XNODE,YNODE,ANGLE,UNITSPD,AAA,DENSITY,MINERND,STEPMINE2
       REAL     MINEPK,MOVE,DEPMINE1,RNG,DEPMINE2,DISTDET2,MINEDET2
       REAL     MINEDET1,PDETONAT4
       REAL*8      DSEED
       DIMENSION  TAIL(150),NODE(150),LOC(10),BLUEDETECT1(10,20)
       DIMENSION  DIST(100),AVE(10,30),SPEED(10,80),DISTDET1(10,100)
       DIMENSION  ANGLE(100),DISTANCE(10),ISTART(10),WIDTH(10),RNG(20)
       DIMENSION  XNODE(150),YNODE(150),BLUEXPOS(20),BLUEYPOS(20)
       DIMENSION  BLUEXOFF1(20),BLUEYOFF1(20),BLUEXOFF2(20),ENTRY1(10)
       DIMENSION  BLUEYOFF2(20),BLUEX1POS(10,20),BLUEY1POS(10,20)
       DIMENSION  UNITSPD(10),VEHTYPE(10,20),BLUECODE(10),MINE1(10)
       DIMENSION  BLUEYOFF0(20),BLUEXOFF0(20),MINERND(100),STATMIN1(10)
       DIMENSION  BLUESTATUS(10,20),CLEAR(20),MOVE(20),DEPMINE1(10)
       DIMENSION  BULL1(10),BYPASS1(10),DISTDET2(10,100),ENTRY2(10)
       DIMENSION  MINE2(10),STATMIN2(10),DEPMINE2(10),BYPASS2(10)
       DIMENSION  BULL2(10),MINEKILL(100),ROLLKILL(100),PLOWKILL(100)
       DIMENSION  PLOWBRCHKILL(100),ROLLBRCHKILL(100),MTYPE(20)

              MINEPK=.99
              STEP=0.1
              STEPMINE2=9.0
              STEPMINE1=9.0
              MINEDET1=0.1
              MINEDET2=0.5
              PCLEAR4=.861
              PCLEAR5=.926
              PDETONAT4=.10
              PSURVIV4=.90
              PSURVIV5=.75
              PDETTNK4=.999
              PDETTNK5=.978

*       PRINT*,'BLUECODE',UNIT,BLUECODE(UNIT),LOC(UNIT)

                 CALL GGUBS(DSEED,100,MINERND)

       DO 70 KOUNT=1,5
           LOC(UNIT)=AVE(UNIT,ISTART(UNIT))
                 IF (BLUECODE(UNIT) .EQ. 0) THEN
                        TRAVEL = 0
                        UNITSPD(UNIT) = 0
                        GO TO 75
                 END IF

           CALL SPD(TRAVEL,SPEED,LOC,STEP,UNIT,UNITSPD,VEHTYPE,NUMBLUE,
     *               AAA,CLOSE,BEHIND,BLUESTATUS)
```

```
      IF (ENTRY1(UNIT) .EQ. 0) THEN
        IF (LOC(UNIT) .EQ. MINE1(UNIT) .AND. STATMIN1(UNIT) .EQ. 1) THEN
            IF (MINERND(1) .LT. MINEDET1) THEN
                    DO 33 K=1,NUMBLUE
                        IF (BLUESTATUS(UNIT,K) .EQ. 2) THEN
                            BLUESTATUS(UNIT,K) = 1
                        END IF
                        IF (VEHTYPE(UNIT,K) .EQ. 2 ) THEN
                             VEHTYPE(UNIT,K) = 4
                        ELSE IF (VEHTYPE(UNIT,K) .EQ. 3 ) THEN
                             VEHTYPE(UNIT,K) = 5
                        END IF
33                  CONTINUE
                        BLUECODE(UNIT)=2
                        CLEAR(UNIT)=3
          MOVE(UNIT)=0.001
                        ENTRY1(UNIT)=1

        WRITE(54,767) CLOCK,UNIT,LOC(UNIT),BLUECODE(UNIT)
767     FORMAT(2X,F4.1,' UNIT ',I1,' DETECTED MINE1 AT ',I3,
     *                                  ' BLUECODE IS ',I1)

                        GO TO 98
            ELSE IF (DISTDET1(UNIT,1) .LT. DISTANCE(UNIT)) THEN
        DO 52 I=1,NUMBLUE
           IF (BLUESTATUS(UNIT,I) .NE. 0) THEN
         RANGE1=(SQRT(((REDX-BLUEX1POS(UNIT,I))**2)+
     *             ((REDY-BLUEY1POS(UNIT,I))**2)))/10
              IF (RANGE1 .LT. STEPMINE1) THEN
                    STEPMINE1=RANGE1
                    ACTIVE1=I
              ELSE IF (RANGE1 .LT. STEPMINE2) THEN
                    STEPMINE2=RANGE1
                    ACTIVE2=I
              END IF
           END IF
52    CONTINUE
                        BLUECODE(UNIT) = 2

        WRITE(54,757) CLOCK,UNIT,LOC(UNIT),BLUECODE(UNIT)
757     FORMAT(2X,F4.1,' UNIT ',I1,' DETONATED MINE1 AT ',I3,
     *                           ' BLUECODE IS ',I1)

              IF (MINERND(2) .LT. MINEPK) THEN
                   BLUESTATUS(UNIT,ACTIVE1)=0
                   MINEKILL(REP)=MINEKILL(REP)+1
         MTYPE(VEHTYPE(UNIT,ACTIVE1))=MTYPE(VEHTYPE(UNIT,ACTIVE1))+1
         WRITE(54,913) UNIT,ACTIVE1,VEHTYPE(UNIT,ACTIVE1)
            IF (DISTDET1(UNIT,2) .LT. DISTANCE(UNIT) .AND.
     *                           MINERND(3) .LT. MINEPK) THEN
                      BLUESTATUS(UNIT,ACTIVE2) = 0
                 MINEKILL(REP)=MINEKILL(REP)+1
         MTYPE(VEHTYPE(UNIT,ACTIVE2))=MTYPE(VEHTYPE(UNIT,ACTIVE2))+1
         WRITE(54,913) UNIT,ACTIVE2,VEHTYPE(UNIT,ACTIVE2)
             END IF


                    DO 35 K=1,NUMBLUE
                        IF (BLUESTATUS(UNIT,K) .EQ. 2) THEN
```

```
                              BLUESTATUS(UNIT,K) = 1
                         END IF
                         IF (VEHTYPE(UNIT,K) .EQ. 2 ) THEN
                              VEHTYPE(UNIT,K) = 4
                         ELSE IF (VEHTYPE(UNIT,K) .EQ. 3 ) THEN
                              VEHTYPE(UNIT,K) = 5
                         END IF
35                  CONTINUE
                          CLEAR(UNIT)=3
                         ENTRY1(UNIT)=1
          MOVE(UNIT)=DISTDET1(UNIT,CLEAR(UNIT))+DISTDET1(UNIT,1)

913        FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' KILLED AT MINEFIELD 1',
     *                  ' MMMMMMMMMMMMMMMMMMMMM')
                         GO TO 98
               END IF
                    DO 59 K=1,NUMBLUE
                         IF (BLUESTATUS(UNIT,K) .EQ. 2) THEN
                              BLUESTATUS(UNIT,K) = 1
                         END IF
                         IF (VEHTYPE(UNIT,K) .EQ. 2 ) THEN
                              VEHTYPE(UNIT,K) = 4
                         ELSE IF (VEHTYPE(UNIT,K) .EQ. 3 ) THEN
                              VEHTYPE(UNIT,K) = 5
                         END IF
59                  CONTINUE
                          CLEAR(UNIT)=3
                         ENTRY1(UNIT)=1
          MOVE(UNIT)=DISTDET1(UNIT,CLEAR(UNIT))+DISTDET1(UNIT,1)

                          GO TO 98
           END IF

        END IF
      ELSE IF (ENTRY2(UNIT) .EQ. 0) THEN
        IF (LOC(UNIT) .EQ. MINE2(UNIT) .AND. STATMIN2(UNIT) .EQ. 1) THEN
            IF (MINERND(1) .LT. MINEDET2) THEN
                    DO 99 K=1,NUMBLUE
                         IF (BLUESTATUS(UNIT,K) .EQ. 2) THEN
                              BLUESTATUS(UNIT,K) = 1
                         END IF
                         IF (VEHTYPE(UNIT,K) .EQ. 2 ) THEN
                              VEHTYPE(UNIT,K) = 4
                         ELSE IF (VEHTYPE(UNIT,K) .EQ. 3 ) THEN
                              VEHTYPE(UNIT,K) = 5
                         END IF
99                  CONTINUE
                         BLUECODE(UNIT)=2
                         CLEAR(UNIT)=3
          MOVE(UNIT)=0.001
                         ENTRY2(UNIT)=1

        WRITE(54,766) CLOCK,UNIT,LOC(UNIT),BLUECODE(UNIT)
766     FORMAT(2X,F4.1,' UNIT ',I1,' DETECTED MINE2 AT ',I3,
     *                                 ' BLUECODE IS ',I1)

                         GO TO 98
            ELSE IF (DISTDET2(UNIT,1) .LT. DISTANCE(UNIT)) THEN
        DO 96 I=1,NUMBLUE
```

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              IF (BLUESTATUS(UNIT,I) .NE. 0) THEN
          RANGE1=(SQRT(((REDX-BLUEX1POS(UNIT,I))**2)+
     *             ((REDY-BLUEY1POS(UNIT,I))**2)))/10
                 IF (RANGE1 .LT. STEPMINE1) THEN
                       STEPMINE1=RANGE1
                       ACTIVE1=I
                 ELSE IF (RANGE1 .LT. STEPMINE2) THEN
                       STEPMINE2=RANGE1
                       ACTIVE2=I
                 END IF
              END IF
96     CONTINUE
                         BLUECODE(UNIT) = 2

         WRITE(54,756) CLOCK,UNIT,LOC(UNIT),BLUECODE(UNIT)
756      FORMAT(2X,F4.1,' UNIT ',I1,' DETONATED MINE2 AT ',I3,
     *                        ' BLUECODE IS ',I1)

*         PRINT*,'UNIT ACTIVE1 MINE2',UNIT,ACTIVE1
                 IF (MINERND(2) .LT. MINEPK) THEN
                      BLUESTATUS(UNIT,ACTIVE1)=0
                      MINEKILL(REP)=MINEKILL(REP)+1
          MTYPE(VEHTYPE(UNIT,ACTIVE1))=MTYPE(VEHTYPE(UNIT,ACTIVE1))+1
          WRITE(54,943) UNIT,ACTIVE1,VEHTYPE(UNIT,ACTIVE1)
              IF (DISTDET2(UNIT,2) .LT. DISTANCE(UNIT) .AND.
     *                           MINERND(3) .LT. MINEPK) THEN
                        BLUESTATUS(UNIT,ACTIVE2) = 0
                      MINEKILL(REP)=MINEKILL(REP)+1
          MTYPE(VEHTYPE(UNIT,ACTIVE2))=MTYPE(VEHTYPE(UNIT,ACTIVE2))+1
          WRITE(54,943) UNIT,ACTIVE2,VEHTYPE(UNIT,ACTIVE2)
               END IF

                       DO 95 K=1,NUMBLUE
                           IF (BLUESTATUS(UNIT,K) .EQ. 2) THEN
                               BLUESTATUS(UNIT,K) = 1
                           END IF
                           IF (VEHTYPE(UNIT,K) .EQ. 2 ) THEN
                                VEHTYPE(UNIT,K) = 4
                           ELSE IF (VEHTYPE(UNIT,K) .EQ. 3 ) THEN
                                VEHTYPE(UNIT,K) = 5
                           END IF
95                     CONTINUE
                            CLEAR(UNIT)=3
                           ENTRY2(UNIT)=1
           MOVE(UNIT)=DISTDET2(UNIT,CLEAR(UNIT))+DISTDET2(UNIT,1)


943       FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' KILLED AT MINEFIELD 2',
     *                   ' MMMMMMMMMMMMMMMMMMMM')
                           GO TO 98
                 END IF
                       DO 94 K=1,NUMBLUE
                           IF (BLUESTATUS(UNIT,K) .EQ. 2) THEN
                               BLUESTATUS(UNIT,K) = 1
                           END IF
                           IF (VEHTYPE(UNIT,K) .EQ. 2 ) THEN
                                VEHTYPE(UNIT,K) = 4
                           ELSE IF (VEHTYPE(UNIT,K) .EQ. 3 ) THEN
                                VEHTYPE(UNIT,K) = 5
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                         END IF
    94               CONTINUE
                          CLEAR(UNIT)=3
                         ENTRY2(UNIT)=1
           MOVE(UNIT)=DISTDET2(UNIT,CLEAR(UNIT))+DISTDET2(UNIT,1)

                          GO TO 98
            END IF

         END IF
       END IF
        IF (ENTRY1(UNIT) .EQ. 2) THEN
         IF (LOC(UNIT) .EQ. MINE1(UNIT)) THEN
                        IF (BULL1(UNIT) .EQ. 1) THEN
                                  GO TO 41
                        ELSE IF (BYPASS1(UNIT) .EQ. 1) THEN
                                  GO TO 46
                        END IF
             IF (BULL1(UNIT) .EQ. 0 .AND. BYPASS1(UNIT) .EQ. 0) THEN
                DO 26 IIPSN=1,NUMBLUE
                   IF (BLUESTATUS(UNIT,IIPSN) .EQ. 0) THEN
                                       GO TO 26
                   ELSE IF (VEHTYPE(UNIT,IIPSN) .EQ. 1) THEN
                      IF (DISTANCE(UNIT) .GE. DEPMINE1(UNIT)/2) THEN
                                      BULL1(UNIT) = 1
                                      GO TO 46
                      ELSE IF (DISTANCE(UNIT) .LT. DEPMINE1(UNIT)/2) THEN
                                      BYPASS1(UNIT) = 1
                                      GO TO 41
                      END IF
                   ELSE IF (VEHTYPE(UNIT,IIPSN) .NE. 1) THEN
                                      GO TO 25
                   END IF
    26          CONTINUE
             END IF

    25      IF (MOVE(UNIT) .LT. DISTANCE(UNIT)) THEN
                  DO 37 IPSN = 1,NUMBLUE
                       IF (BLUESTATUS(UNIT,IPSN) .EQ. 0) THEN
                       GO TO 37
                       END IF
                 IF (VEHTYPE(UNIT,IPSN) .EQ. 1) THEN
                        IF (MINERND(CLEAR(UNIT)) .LT. MINEPK) THEN
                        BLUESTATUS(UNIT,IPSN) = 0
                      MINEKILL(REP)=MINEKILL(REP)+1
                   MTYPE(VEHTYPE(UNIT,IPSN))=MTYPE(VEHTYPE(UNIT,IPSN))+1
        WRITE(54,940) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
    940 FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' KILLED IN MINEFIELD 1 ',
      *            'DUE TO UNCLEARED MINE')
                        GO TO 36
                        ELSE IF (MINERND(CLEAR(UNIT)) .GE. MINEPK) THEN
                        GO TO 36
                        END IF
                 ELSE IF (VEHTYPE(UNIT,IPSN) .EQ. 4) THEN
                      IF (MINERND(CLEAR(UNIT)) .LT. PCLEAR4) THEN
                        CLEAR(UNIT)= CLEAR(UNIT) + 1
                         IF (MINERND(CLEAR(UNIT)) .GE. PDETONAT4) THEN
        WRITE(54,641) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
    641 FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' CLEARED A MINE',
      *            ' IN MINEFIELD 1 SSSS')
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                    CLEAR(UNIT)= CLEAR(UNIT) + 1
                       GO TO 36
                ELSE IF (MINERND(CLEAR(UNIT)) .LT. PDETONAT4) THEN
                    CLEAR(UNIT)= CLEAR(UNIT) + 1
                     IF (MINERND(CLEAR(UNIT)) .LT. PSURVIV4) THEN
      WRITE(54,941) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
941   FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' CLEARED/SURVIVED BLAST',
     *            ' IN MINEFIELD 1 SSSS')
                       GO TO 36
                   ELSE IF (MINERND(CLEAR(UNIT)) .GE. PSURVIV4) THEN
      WRITE(54,942) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
942   FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' CLEARED/PLOW DID NOT ',
     *            ' SURVIVE IN MINEFIELD 1')
                       PLOWKILL(REP)=PLOWKILL(REP)+1
                       VEHTYPE(UNIT,IPSN) = 1
                       TEMPTYPE=VEHTYPE(UNIT,IPSN)
                       TEMPSTATUS=BLUESTATUS(UNIT,IPSN)
                       TEMPDETECT=BLUEDETECT1(UNIT,IPSN)
                              DO 61 PSN=IPSN,NUMBLUE-1
                             VEHTYPE(UNIT,PSN)=VEHTYPE(UNIT,PSN+1)
                        BLUESTATUS(UNIT,PSN)= BLUESTATUS(UNIT,PSN+1)
                        BLUEDETECT1(UNIT,PSN)=BLUEDETECT1(UNIT,PSN+1)
61                           CONTINUE
                       BLUESTATUS(UNIT,NUMBLUE)=TEMPSTATUS
                       VEHTYPE(UNIT,NUMBLUE)=TEMPTYPE
                       BLUEDETECT1(UNIT,NUMBLUE)=TEMPDETECT
                       GO TO 36
                   END IF
                END IF
         ELSE IF (MINERND(CLEAR(UNIT)) .LT. PDETTNK4 .AND.
     *                 MINERND(CLEAR(UNIT)) .GT. PCLEAR4)  THEN
                         CLEAR(UNIT)=CLEAR(UNIT)+1
                 IF (MINERND(CLEAR(UNIT)) .LT. MINEPK) THEN
      WRITE(54,945) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
945   FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' PLOW FAILED TO CLEAR ',
     *            'MINE/CARRIER WAS KILLED')
                BLUESTATUS(UNIT,IPSN) = 0
                PLOWBRCHKILL(REP)=PLOWBRCHKILL(REP)+1
                GO TO 36
                ELSE IF (MINERND(CLEAR(UNIT)) .GE. MINEPK) THEN
                GO TO 36
                END IF
         ELSE IF (MINERND(CLEAR(UNIT)) .GE. PDETTNK4) THEN
                         CLEAR(UNIT)=CLEAR(UNIT)+1
      WRITE(54,946) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
946   FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' PLOW FAILED TO CLEAR ',
     *            'MINE/CARRIER SURVIVED')
      WRITE(54,947)
947   FORMAT('MINE LEFT IN PATH UNEXPLODED')
                        GO TO 37
         END IF
        ELSE IF (VEHTYPE(UNIT,IPSN) .EQ. 5) THEN
         IF (MINERND(CLEAR(UNIT)) .LT. PCLEAR5) THEN
           CLEAR(UNIT)= CLEAR(UNIT) + 1
          IF (MINERND(CLEAR(UNIT)) .LT. PSURVIV5) THEN
      WRITE(54,901) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
901   FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' CLEARED/SURVIVED A MINE',
     *            ' IN MINEFIELD 1 SSSS')
                     GO TO 36
          ELSE IF (MINERND(CLEAR(UNIT)) .GE. PSURVIV5) THEN
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      WRITE(54,944) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
944   FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' CLEARED/ROLLER DIDNOT',
     *           ' SURVIVE IN MINEFIELD 1')
                  ROLLKILL(REP)=ROLLKILL(REP)+1
                      VEHTYPE(UNIT,IPSN) = 1
                      TEMPTYPE=VEHTYPE(UNIT,IPSN)
                      TEMPSTATUS=BLUESTATUS(UNIT,IPSN)
                      TEMPDETECT=BLUEDETECT1(UNIT,IPSN)
        DO 65 PSN=IPSN,NUMBLUE-1
              VEHTYPE(UNIT,PSN)=VEHTYPE(UNIT,PSN+1)
              BLUESTATUS(UNIT,PSN)= BLUESTATUS(UNIT,PSN+1)
              BLUEDETECT1(UNIT,PSN)=BLUEDETECT1(UNIT,PSN+1)
65                CONTINUE
              BLUESTATUS(UNIT,NUMBLUE)=TEMPSTATUS
              VEHTYPE(UNIT,NUMBLUE)=TEMPTYPE
              BLUEDETECT1(UNIT,NUMBLUE)=TEMPDETECT
                     GO TO 36
             END IF
           ELSE IF (MINERND(CLEAR(UNIT)) .LT. PDETTNK5 .AND.
     *                 MINERND(CLEAR(UNIT)) .GT. PCLEAR5)  THEN
                           CLEAR(UNIT)=CLEAR(UNIT)+1
               IF (MINERND(CLEAR(UNIT)) .LT. MINEPK) THEN
                      BLUESTATUS(UNIT,IPSN) = 0
      WRITE(54,955) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
955   FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' ROLLER FAILED TO CLEAR ',
     *           'MINE/CARRIER WAS KILLED')
                ROLLBRCHKILL(REP)=ROLLBRCHKILL(REP)+1
                           GO TO 36
                ELSE IF (MINERND(CLEAR(UNIT)) .GE. MINEPK) THEN
                            GO TO 36
                END IF
           ELSE IF (MINERND(CLEAR(UNIT)) .GE. PDETTNK5) THEN
                           CLEAR(UNIT)=CLEAR(UNIT)+1
      WRITE(54,948) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
948   FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' ROLLER FAILED TO CLEAR ',
     *           'MINE/CARRIER SURVIVED')
      WRITE(54,949)
949   FORMAT('MINE LEFT IN PATH UNEXPLODED')
                          GO TO 37
           END IF
           END IF
37     CONTINUE
36                         CLEAR(UNIT)=CLEAR(UNIT)+1
                      MOVE(UNIT)=DISTDET1(UNIT,CLEAR(UNIT))+MOVE(UNIT)
           IF (DISTANCE(UNIT) .GT. DEPMINE1(UNIT)) THEN
                                 ENTRY1(UNIT)=3
             IF (BLUECODE(UNIT) .NE. 0) THEN
                       BLUECODE(UNIT) = 1
                     DO 38 K=1,NUMBLUE
               IF (VEHTYPE(UNIT,K) .EQ. 4 ) THEN
                            VEHTYPE(UNIT,K) = 2
               ELSE IF (VEHTYPE(UNIT,K) .EQ. 5 ) THEN
                            VEHTYPE(UNIT,K) = 3
               END IF
38      CONTINUE
             END IF
           END IF
         END IF
       END IF
     END IF
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41        IF (BULL1(UNIT).EQ. 1) THEN
                         TRAVEL=TRAVEL/10
             IF(MOVE(UNIT) .LT. DISTANCE(UNIT)) THEN
                DO 21 IPSN = 1,NUMBLUE
                    IF (BLUESTATUS(UNIT,IPSN) .EQ. 0) THEN
                       GO TO 21
                    END IF
                    IF (MINERND(CLEAR(UNIT)) .LT. MINEPK) THEN
                        BLUESTATUS(UNIT,IPSN) = 0
                        MINEKILL(REP)=MINEKILL(REP)+1
                   MTYPE(VEHTYPE(UNIT,IPSN))=MTYPE(VEHTYPE(UNIT,IPSN))+1
        WRITE(54,967) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
967     FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' KILLED IN MINEFIELD 1 ',
     *            'DUE TO BULLING THRU ')
                        GO TO 71
                     ELSE IF (MINERND(CLEAR(UNIT)) .GE. MINEPK) THEN
                        GO TO 71
                     END IF
21              CONTINUE
71                           CLEAR(UNIT)=CLEAR(UNIT)+1
                        MOVE(UNIT)=DISTDET1(UNIT,CLEAR(UNIT))+MOVE(UNIT)
             IF (DISTANCE(UNIT) .GT. DEPMINE1(UNIT)) THEN
                                   ENTRY1(UNIT)=3
               IF (BLUECODE(UNIT) .NE. 0) THEN
                         BLUECODE(UNIT) = 1
                        BULL1(UNIT) = 2
                        GO TO 75
              END IF
             END IF
          END IF
              END IF

46        IF (BYPASS1(UNIT).EQ. 1) THEN
                         TRAVEL=TRAVEL/40
                IF (KOUNT .EQ.5) THEN
        WRITE(54,968) UNIT
968     FORMAT(' UNIT ',I3,' IS CONDUCTING BYPASS OPERATION AROUND ',
     *           'MINEFIELD 1 PPPPPPP ')
                END IF
             IF (DISTANCE(UNIT) .GT. DEPMINE1(UNIT)) THEN
                                   ENTRY1(UNIT)=3
               IF (BLUECODE(UNIT) .NE. 0) THEN
                         BLUECODE(UNIT) = 1
                        BYPASS1(UNIT) = 2
          END IF
          END IF
             END IF


        IF (ENTRY2(UNIT) .EQ. 2) THEN
         IF (LOC(UNIT) .EQ. MINE2(UNIT)) THEN
                        IF (BULL2(UNIT) .EQ. 1) THEN
                                  GO TO 93
                        ELSE IF (BYPASS2(UNIT) .EQ. 1) THEN
                                  GO TO 92
                        END IF
             IF (BULL2(UNIT) .EQ. 0 .AND. BYPASS2(UNIT) .EQ. 0) THEN
                DO 91 IIPSN=1,NUMBLUE
                   IF (BLUESTATUS(UNIT,IIPSN) .EQ. 0) THEN
                                       GO TO 91
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                 ELSE IF (VEHTYPE(UNIT,IIPSN) .EQ. 1) THEN
                    IF (DISTANCE(UNIT) .GE. DEPMINE2(UNIT)/2) THEN
                                    BULL2(UNIT) = 1
                                    GO TO 92
                    ELSE IF (DISTANCE(UNIT) .LT. DEPMINE2(UNIT)/2) THEN
                                    BYPASS2(UNIT) = 1
                                    GO TO 93
                    END IF
                 ELSE IF (VEHTYPE(UNIT,IIPSN) .NE. 1) THEN
                                    GO TO 72
                 END IF
 91            CONTINUE
             END IF
 72         IF (MOVE(UNIT) .LT. DISTANCE(UNIT)) THEN
                DO 73 IPSN = 1,NUMBLUE
                     IF (BLUESTATUS(UNIT,IPSN) .EQ. 0) THEN
                     GO TO 73
                     END IF
               IF (VEHTYPE(UNIT,IPSN) .EQ. 1) THEN
                      IF (MINERND(CLEAR(UNIT)) .LT. MINEPK) THEN
                      BLUESTATUS(UNIT,IPSN) = 0
                      MINEKILL(REP)=MINEKILL(REP)+1
                 MTYPE(VEHTYPE(UNIT,IPSN))=MTYPE(VEHTYPE(UNIT,IPSN))+1
        WRITE(54,741) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
 741    FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' KILLED IN MINEFIELD 2 ',
     *           'DUE TO UNCLEARED MINE')
                      GO TO 78
                      ELSE IF (MINERND(CLEAR(UNIT)) .GE. MINEPK) THEN
                      GO TO 78
                      END IF
               ELSE IF (VEHTYPE(UNIT,IPSN) .EQ. 4) THEN
                      IF (MINERND(CLEAR(UNIT)) .LT. PCLEAR4) THEN
                      CLEAR(UNIT)= CLEAR(UNIT) + 1
                       IF (MINERND(CLEAR(UNIT)) .GE. PDETONAT4) THEN
        WRITE(54,341) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
 341    FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' CLEARED A MINE',
     *           ' IN MINEFIELD 2 SSSS')
                      CLEAR(UNIT)= CLEAR(UNIT) + 1
                         GO TO 78
                   ELSE IF (MINERND(CLEAR(UNIT)) .LT. PDETONAT4) THEN
                      CLEAR(UNIT)= CLEAR(UNIT) + 1
                       IF (MINERND(CLEAR(UNIT)) .LT. PSURVIV4) THEN
        WRITE(54,981) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
 981    FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' CLEARED/SURVIVED BLAST',
     *           ' IN MINEFIELD 2 SSSS')
                         GO TO 78
                     ELSE IF (MINERND(CLEAR(UNIT)) .GE. PSURVIV4) THEN
        WRITE(54,982) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
 982    FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' CLEARED/PLOW DID NOT ',
     *           ' SURVIVE IN MINEFIELD 2')
                        PLOWKILL(REP)=PLOWKILL(REP)+1
                         VEHTYPE(UNIT,IPSN) = 1
                         TEMPTYPE=VEHTYPE(UNIT,IPSN)
                         TEMPSTATUS=BLUESTATUS(UNIT,IPSN)
                         TEMPDETECT=BLUEDETECT1(UNIT,IPSN)
                                DO 53 PSN=IPSN,NUMBLUE-1
                               VEHTYPE(UNIT,PSN)=VEHTYPE(UNIT,PSN+1)
                          BLUESTATUS(UNIT,PSN)= BLUESTATUS(UNIT,PSN+1)
                          BLUEDETECT1(UNIT,PSN)=BLUEDETECT1(UNIT,PSN+1)
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 53                          CONTINUE
                       BLUESTATUS(UNIT,NUMBLUE)=TEMPSTATUS
                       VEHTYPE(UNIT,NUMBLUE)=TEMPTYPE
                       BLUEDETECT1(UNIT,NUMBLUE)=TEMPDETECT
                       GO TO 78
                   END IF
              END IF
         ELSE IF (MINERND(CLEAR(UNIT)) .LT. PDETTNK4 .AND.
     *               MINERND(CLEAR(UNIT)) .GT. PCLEAR4)  THEN
                       CLEAR(UNIT)=CLEAR(UNIT)+1
               IF (MINERND(CLEAR(UNIT)) .LT. MINEPK) THEN
    WRITE(54,975) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
975 FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' PLOW FAILED TO CLEAR ',
     *          'MINE/CARRIER WAS KILLED')
              BLUESTATUS(UNIT,IPSN) = 0
              PLOWBRCHKILL(REP)=PLOWBRCHKILL(REP)+1
              GO TO 78
              ELSE IF (MINERND(CLEAR(UNIT)) .GE. MINEPK) THEN
              GO TO 78
              END IF
         ELSE IF (MINERND(CLEAR(UNIT)) .GE. PDETTNK4) THEN
                       CLEAR(UNIT)=CLEAR(UNIT)+1
    WRITE(54,976) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
976 FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' PLOW FAILED TO CLEAR ',
     *          'MINE/CARRIER SURVIVED')
    WRITE(54,937)
937 FORMAT('MINE LEFT IN PATH UNEXPLODED')
                          GO TO 73
         END IF
       ELSE IF (VEHTYPE(UNIT,IPSN) .EQ. 5) THEN
         IF (MINERND(CLEAR(UNIT)) .LT. PCLEAR5) THEN
             CLEAR(UNIT)= CLEAR(UNIT) + 1
           IF (MINERND(CLEAR(UNIT)) .LT. PSURVIV5) THEN
    WRITE(54,933) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
933 FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' CLEARED/SURVIVED A MINE',
     *          ' IN MINEFIELD 2 SSSS')
                  GO TO 78
           ELSE IF (MINERND(CLEAR(UNIT)) .GE. PSURVIV5) THEN
    WRITE(54,934) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
934 FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' CLEARED/ROLLER DIDNOT',
     *          ' SURVIVE IN MINEFIELD 2')
              ROLLKILL(REP)=ROLLKILL(REP)+1
                  VEHTYPE(UNIT,IPSN) = 1
                  TEMPTYPE=VEHTYPE(UNIT,IPSN)
                  TEMPSTATUS=BLUESTATUS(UNIT,IPSN)
                  TEMPDETECT=BLUEDETECT1(UNIT,IPSN)
        DO 45 PSN=IPSN,NUMBLUE-1
              VEHTYPE(UNIT,PSN)=VEHTYPE(UNIT,PSN+1)
              BLUESTATUS(UNIT,PSN)= BLUESTATUS(UNIT,PSN+1)
              BLUEDETECT1(UNIT,PSN)=BLUEDETECT1(UNIT,PSN+1)
 45               CONTINUE
              BLUESTATUS(UNIT,NUMBLUE)=TEMPSTATUS
              VEHTYPE(UNIT,NUMBLUE)=TEMPTYPE
              BLUEDETECT1(UNIT,NUMBLUE)=TEMPDETECT
                  GO TO 78
           END IF
         ELSE IF (MINERND(CLEAR(UNIT)) .LT. PDETTNK5 .AND.
     *               MINERND(CLEAR(UNIT)) .GT. PCLEAR5)  THEN
                       CLEAR(UNIT)=CLEAR(UNIT)+1
             IF (MINERND(CLEAR(UNIT)) .LT. MINEPK) THEN
```

```
                           BLUESTATUS(UNIT,IPSN) = 0
          WRITE(54,935) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
935       FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' ROLLER FAILED TO CLEAR ',
     *               'MINE/CARRIER WAS KILLED')
                    ROLLBRCHKILL(REP)=ROLLBRCHKILL(REP)+1
                               GO TO 78
                    ELSE IF (MINERND(CLEAR(UNIT)) .GE. MINEPK) THEN
                                GO TO 78
                    END IF
               ELSE IF (MINERND(CLEAR(UNIT)) .GE. PDETTNK5) THEN
                               CLEAR(UNIT)=CLEAR(UNIT)+1
          WRITE(54,938) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
938       FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' ROLLER FAILED TO CLEAR ',
     *               'MINE/CARRIER SURVIVED')
          WRITE(54,939)
939       FORMAT('MINE LEFT IN PATH UNEXPLODED')
                              GO TO 73
               END IF
               END IF
73         CONTINUE
                               CLEAR(UNIT)=CLEAR(UNIT)+1
                          MOVE(UNIT)=DISTDET2(UNIT,CLEAR(UNIT))+MOVE(UNIT)
               IF (DISTANCE(UNIT) .GT. DEPMINE2(UNIT)) THEN
                                     ENTRY2(UNIT)=3
                 IF (BLUECODE(UNIT) .NE. 0) THEN
                           BLUECODE(UNIT) = 1
                         DO 48 K=1,NUMBLUE
                   IF (VEHTYPE(UNIT,K) .EQ. 4 ) THEN
                                VEHTYPE(UNIT,K) = 2
                   ELSE IF (VEHTYPE(UNIT,K) .EQ. 5 ) THEN
                                VEHTYPE(UNIT,K) = 3
                   END IF
48          CONTINUE
                 END IF
               END IF
             END IF
           END IF
         END IF
93          IF (BULL2(UNIT).EQ. 1) THEN
                           TRAVEL=TRAVEL/10
               IF(MOVE(UNIT) .LT. DISTANCE(UNIT)) THEN
                  DO 82 IPSN = 1,NUMBLUE
                      IF (BLUESTATUS(UNIT,IPSN) .EQ. 0) THEN
                         GO TO 82
                      END IF
                      IF (MINERND(CLEAR(UNIT)) .LT. MINEPK) THEN
                          BLUESTATUS(UNIT,IPSN) = 0
                      MINEKILL(REP)=MINEKILL(REP)+1
                     MTYPE(VEHTYPE(UNIT,IPSN))=MTYPE(VEHTYPE(UNIT,IPSN))+1
          WRITE(54,957) UNIT,IPSN,VEHTYPE(UNIT,IPSN)
957       FORMAT(' VEHICLE ',2I3,' VEHTYPE ',I3,' KILLED IN MINEFIELD 2 ',
     *               'DUE TO BULLING THRU ')
                          GO TO 84
                       ELSE IF (MINERND(CLEAR(UNIT)) .GE. MINEPK) THEN
                          GO TO 84
                       END IF
82                CONTINUE
84                             CLEAR(UNIT)=CLEAR(UNIT)+1
                          MOVE(UNIT)=DISTDET2(UNIT,CLEAR(UNIT))+MOVE(UNIT)
               IF (DISTANCE(UNIT) .GT. DEPMINE2(UNIT)) THEN
```

```
                                    ENTRY2(UNIT)=3
                    IF (BLUECODE(UNIT) .NE. 0) THEN
                              BLUECODE(UNIT) = 1
                             BULL2(UNIT) = 2
                             GO TO 75
                   END IF
                  END IF
               END IF
                   END IF

   92          IF (BYPASS2(UNIT).EQ. 1) THEN
                              TRAVEL=TRAVEL/50
                     IF (KOUNT .EQ.5) THEN
             WRITE(54,977) UNIT
   977       FORMAT(' UNIT ',I3,' IS CONDUCTING BYPASS OPERATION AROUND ',
     *                  'MINEFIELD 2 PPPPPPP ')
                     END IF
                  IF (DISTANCE(UNIT) .GT. DEPMINE2(UNIT)) THEN
                                    ENTRY2(UNIT)=3
                    IF (BLUECODE(UNIT) .NE. 0) THEN
                              BLUECODE(UNIT) = 1
                             BYPASS2(UNIT) = 2
               END IF
               END IF
                  END IF


   75               DELX=TRAVEL*COS(ANGLE(LOC(UNIT)))*10
                    DELY=TRAVEL*SIN(ANGLE(LOC(UNIT)))*10
                    BLUEXPOS(UNIT)=BLUEXPOS(UNIT)+DELX
                    BLUEYPOS(UNIT)=BLUEYPOS(UNIT)+DELY

               CALL OFFSET (BLUEXPOS,BLUEYPOS,BLUEXOFF1,BLUEYOFF1,LOC,
     *                       ANGLE,UNIT,NUMBLUE,CLOCK,KOUNT,BLUECODE,
     *                       BLUEXOFF2,BLUEYOFF2,BLUEX1POS,BLUEY1POS,
     *                       BLUEXOFF0,BLUEYOFF0)

                    DISTANCE(UNIT)=DISTANCE(UNIT)+TRAVEL

            IF (DISTANCE(UNIT) .GE. DIST(LOC(UNIT))) THEN
                    ISTART(UNIT)=ISTART(UNIT)+1
                    LOC(UNIT) = AVE(UNIT,ISTART(UNIT))
                    DISTANCE(UNIT)=0.0
                 BLUEXPOS(UNIT) = XNODE(TAIL(LOC(UNIT)))
                 BLUEYPOS(UNIT) = YNODE(TAIL(LOC(UNIT)))
                 GO TO 98
             END IF
   70           CONTINUE
              GO TO 98

             WRITE(54,931) CLOCK,UNIT,LOC(UNIT),BLUEXPOS(UNIT),BLUEYPOS(UNIT),
     *                    UNITSPD(UNIT),RNG(UNIT)
   931          FORMAT(2X,F4.1,' UNIT ',I3,' LOC ',I3,
     *                ' POSITION ',2F6.1,' SPEED ',F4.0,' RANGE ',F8.3)

   98            RETURN
                 END
```

****

```
****************  SPEED  ******************************************
      SUBROUTINE SPD(TRAVEL,SPEED,LOC,STEP,UNIT,UNITSPD,VEHTYPE,
     *             NUMBLUE,AAA,CLOSE,BEHIND,BLUESTATUS)
           INTEGER LOC,UNIT,VEHTYPE,NUMBLUE,VEH,CLOSE,BEHIND
           INTEGER BLUESTATUS
           REAL  SPEED,TRAVEL,STEP,UNITSPD,AAA
           DIMENSION SPEED(10,80),LOC(10),UNITSPD(10),VEHTYPE(10,20)
           DIMENSION BLUESTATUS(10,20)

                  UNITSPD(UNIT)=160

         DO 23 VEH=1,NUMBLUE
      IF(BLUESTATUS(UNIT,VEH) .NE. 0) THEN
      IF(SPEED(VEHTYPE(UNIT,VEH),LOC(UNIT)) .LT. UNITSPD(UNIT)) THEN
                  UNITSPD(UNIT)=SPEED(VEHTYPE(UNIT,VEH),LOC(UNIT))

              END IF
              END IF
 23      CONTINUE

       IF (BEHIND .EQ. 1 .AND. CLOSE .EQ. UNIT) THEN
            UNITSPD(UNIT) = UNITSPD(UNIT)/AAA
            TRAVEL = (UNITSPD(UNIT)/60)*STEP
            GO TO 51
       END IF

            TRAVEL = (UNITSPD(UNIT)/60)*STEP

 51         RETURN
              END

******************************************************************
```

```
********************* OFFSET ************************************

      SUBROUTINE OFFSET (BLUEXPOS,BLUEYPOS,BLUEXOFF1,BLUEYOFF1,
     *          LOC,ANGLE,UNIT,NUMBLUE,CLOCK,KOUNT,
     *          BLUECODE,BLUEXOFF2,BLUEYOFF2,BLUEX1POS,BLUEY1POS,
     *          BLUEXOFF0,BLUEYOFF0)

      INTEGER LOC,UNIT,C,KOUNT,NUMBLUE,BLUECODE
      REAL BLUEX1PLT,BLUEY1PLT,ANGLE,BLUEXPOS,BLUEYPOS
      REAL XOFFPLT,YOFFPLT,CLOCK
      REAL BLUEXOFF1,BLUEXOFF2,BLUEYOFF1,BLUEYOFF2,BLUEX1POS,BLUEY1POS
      REAL BLUEXOFF0,BLUEYOFF0
      DIMENSION BLUEXOFF1(20),BLUEYOFF1(20),ANGLE(100),BLUECODE(10)
      DIMENSION BLUEXOFF0(20),BLUEYOFF0(20)
      DIMENSION BLUEX1POS(10,20),BLUEY1POS(10,20),LOC(10)
      DIMENSION BLUEXPOS(20),BLUEYPOS(20),BLUEXOFF2(20),BLUEYOFF2(20)

        DO 60 C=1,NUMBLUE
       IF (BLUECODE(UNIT) .EQ. 0) THEN
           XOFFPLT=BLUEXOFF0(C)
           YOFFPLT=BLUEYOFF0(C)
       ELSE IF (BLUECODE(UNIT) .EQ. 1) THEN
           XOFFPLT=BLUEXOFF1(C)
           YOFFPLT=BLUEYOFF1(C)
       ELSE IF (BLUECODE(UNIT) .EQ. 2) THEN
           XOFFPLT=BLUEXOFF2(C)
           YOFFPLT=BLUEYOFF2(C)
       END IF
        BLUEX1POS(UNIT,C)=BLUEXPOS(UNIT)+(XOFFPLT*COS(ANGLE(LOC(UNIT)))
     *                    +YOFFPLT*SIN(ANGLE(LOC(UNIT))))
        BLUEY1POS(UNIT,C)=BLUEYPOS(UNIT)+(-XOFFPLT*SIN(ANGLE(LOC(UNIT)))
     *                    +YOFFPLT*COS(ANGLE(LOC(UNIT))))

   60   CONTINUE


           RETURN
              END
******************************************************************
```

**************** DETECTION **********************************

```
      SUBROUTINE REDDETECT (REDXPOS,REDYPOS,BLUEXPOS,BLUEYPOS,
     *           BLUEX1POS,BLUEY1POS,NUNIT,REDENGAGE,BLUESTATUS,
     *           ANGLE,UNIT,UNITSPD,CLOCK,LOC,CV,NUMRED,NUMBLUE,
     *           REDX,REDY,RED,RPLOOK,REDSTATUS,DSEED,VEHTYPE,
     *           REDDETECT1,REDDETECT2,ELEMENT,POSITION,TAU,
     *           RVEHTYP,BLUECODE,RMAX)

      INTEGER UNIT,LOC,NUMRED,RED,REDSTATUS,VEHTYPE,REDENGAGE
      INTEGER REDDETECT1,REDDETECT2,ELEMENT,POSITION,NUNIT
      INTEGER BLUESTATUS,RVEHTYP,BLUECODE
      REAL REDXPOS,REDYPOS,BLUEXPOS,BLUEYPOS
      REAL BLUEX1POS,BLUEY1POS,ANGLE,UNITSPD
      REAL CLOCK,CV,REDX,REDY,HEIGHT,TAU,DENOM,RPLOOK,REDPDET
      REAL RAND,RMAX,RAF,RNGADJ,RNGDET1,RNGDET2,RANGE1,RANGE2
      REAL*8 DSEED
   DIMENSION  BLUEXPOS(20),BLUEYPOS(20),LOC(10),UNITSPD(10),CV(10)
   DIMENSION  BLUEX1POS(10,20),BLUEY1POS(10,20),ANGLE(100)
   DIMENSION  RED(30),REDXPOS(30),REDYPOS(30),RPLOOK(10,30)
   DIMENSION  RAND(10),REDSTATUS(30),RMAX(30),TEMP(30)
   DIMENSION  VEHTYPE(10,20),HEIGHT(20),RAF(8),REDENGAGE(100)
   DIMENSION  REDDETECT1(30),REDDETECT2(30),RNGDET1(30),RNGDET2(30)
   DIMENSION  BLUESTATUS(10,20),RVEHTYP(30),BLUECODE(10)

      HEIGHT(1)=2.4
      HEIGHT(2)=2.4
      HEIGHT(3)=2.4
      HEIGHT(4)=2.4
      HEIGHT(5)=2.4

       RNGDET1(ELEMENT)=300.0
       RANGE1=0.0
       RNGDET2(ELEMENT)=500.0
       RANGE2=0.0
       REDDETECT1(ELEMENT)=0
       REDDETECT2(ELEMENT)=0


          DO 39 I=1,3
             RAF(I)=.000
39    CONTINUE
             RAF(4)=.10
             RAF(5)=.10
```

```
*  LOOP 77 NUMBER OF BLUE UNITS
            DO 77 UNIT=1,NUNIT

         IF (BLUECODE(UNIT) .EQ. 0 ) THEN
                  CV(UNIT) = 0
                  GO TO 66
         END IF
                OBSVECX=REDX-BLUEXPOS(UNIT)
                OBSVECY=REDY-BLUEYPOS(UNIT)
                DIRVECX=COS(ANGLE(LOC(UNIT)))
                DIRVECY=SIN(ANGLE(LOC(UNIT)))
              OBSVECL=SQRT((OBSVECX**2)+(OBSVECY**2))
              CVANGLE=ACOS(((OBSVECX*DIRVECX)+(OBSVECY*DIRVECY))/OBSVECL)
              CV(UNIT) = (UNITSPD(UNIT)*1000/3600)*SIN(CVANGLE)


*  LOOP 79 NUMBER OF BLUE ELEMENTS IN EACH UNIT
66                DO 79  POSITION=1,NUMBLUE
                         IF (BLUESTATUS(UNIT,POSITION) .EQ. 0) THEN
                                 GO TO 79
                         END IF

                    CALL GGUBS(DSEED,3,RAND)

            RANGE=(SQRT(((REDXPOS(ELEMENT)-BLUEX1POS(UNIT,POSITION))**2)+
     *                ((REDYPOS(ELEMENT)-BLUEY1POS(UNIT,POSITION))**2)))/10
              IF (BLUECODE(UNIT) .EQ. 0) THEN
          RNGAPP=(RANGE*2.8)/(((HEIGHT(VEHTYPE(UNIT,POSITION))/2)*RAND(1))
     *                             +(HEIGHT(VEHTYPE(UNIT,POSITION))/4))
                  GO TO 55
              END IF

          RNGAPP=(RANGE*2.8)/(((HEIGHT(VEHTYPE(UNIT,POSITION))/2)*RAND(1))
     *                             +(HEIGHT(VEHTYPE(UNIT,POSITION))/2))

55              IF (RANGE .LT. .250) THEN
                        REDPDET=1.0
                       GO TO 34
                END IF

                     DENOM=1.453+(TAU*(.05978+(2.188*RNGAPP*RNGAPP)-
     *                         .5038*CV(UNIT)))
                     DETRATE=RPLOOK(UNIT,ELEMENT)*(-.003+(1.088/DENOM))

                 IF (DETRATE .LE. 0.0) THEN
                  DETRATE = 0.0
                 ELSE IF (DETRATE .GT. 5.0) THEN
                  REDPDET=1.0
                  GO TO 34
                 END IF

                     REDPDET=1-EXP(-DETRATE*30)
34       IF (REDENGAGE(((NUMBLUE*(UNIT-1))+POSITION)) .GE. 2) THEN
                   GO TO 79
                  END IF

            IF (REDPDET .GE. RAND(2)) THEN
             IF (RANGE .LE. RMAX(ELEMENT)) THEN
```

```
          RNGADJ=(RANGE/(1-(RAND(3)/2))) + RAF(VEHTYPE(UNIT,POSITION))

              IF (RNGADJ .LT. RNGDET1(ELEMENT)) THEN
                     RNGDET1(ELEMENT) = RNGADJ
                     RANGE1=RANGE
                       REDSTATUS(ELEMENT) = 2
               REDDETECT1(ELEMENT)=(NUMBLUE*(UNIT-1))+POSITION
              ELSE IF (RNGADJ .LT. RNGDET2(ELEMENT)) THEN
                 IF(RVEHTYP(ELEMENT) .EQ. 1) THEN
                     RNGDET2(ELEMENT) = RNGADJ
                     RANGE2=RANGE
                       REDSTATUS(ELEMENT) = 2
                    REDDETECT2(ELEMENT)= (NUMBLUE*(UNIT-1))+POSITION
                  END IF
              END IF
          END IF
      END IF

 79    CONTINUE
 77    CONTINUE
         IF (RNGDET1(ELEMENT) .LT. 200.0) THEN
       REDENGAGE(REDDETECT1(ELEMENT))=REDENGAGE(REDDETECT1(ELEMENT))+1
         END IF
         IF (RNGDET2(ELEMENT) .LT. 200.0) THEN

       REDENGAGE(REDDETECT2(ELEMENT))=REDENGAGE(REDDETECT2(ELEMENT))+1

          END IF

         RETURN
          END

**********************************************************************

          SUBROUTINE BLUEDETECT (REDXPOS,REDYPOS,BLUEX1POS,BLUEY1POS,
     *         BLUEENGAGE,BLUESTATUS,REDSTATUS,DSEED,UNIT,CLOCK,NUMRED,
     *         BLUEDETECT1,ELEMENT,POSITION,TAU,RVEHTYP,RHEIGHT,RRAF,
     *         BLUERMAX)
          INTEGER UNIT,NUMRED,REDSTATUS
          INTEGER BLUEDETECT1,ELEMENT,POSITION
          INTEGER BLUESTATUS,RVEHTYP,BLUEENGAGE
          REAL REDXPOS,REDYPOS
          REAL BLUEX1POS,BLUEY1POS,DETRATE
          REAL CLOCK,RHEIGHT,TAU,DENOM,RNGAPP,RANGE,BLUEPDET
          REAL RUND,BLUERMAX,RRAF,RNGADJ,RNGDET,RANGE1
          REAL*8 DSEED
       DIMENSION  BLUEX1POS(10,20),BLUEY1POS(10,20)
       DIMENSION  REDXPOS(30),REDYPOS(30)
       DIMENSION  RUND(10),REDSTATUS(30),BLUERMAX(10,20)
       DIMENSION  BLUEDETECT1(10,20),RNGDET(10,20),BLUEENGAGE(30)
       DIMENSION  BLUESTATUS(10,20),RVEHTYP(30),RRAF(4),RHEIGHT(30)

       RNGDET(UNIT,POSITION)=300
       RANGE1=0.0
       BLUEDETECT1(UNIT,POSITION)=0

       DO 29 ELEMENT=1,NUMRED
```

```
                  IF(REDSTATUS(ELEMENT) .EQ. 0) THEN
                       GO TO 29
                  END IF
                     CALL GGUBS(DSEED,3,RUND)

             RANGE=(SQRT(((REDXPOS(ELEMENT)-BLUEX1POS(UNIT,POSITION))**2)+
     *              ((REDYPOS(ELEMENT)-BLUEY1POS(UNIT,POSITION))**2)))/10

           RNGAPP=(RANGE*2.8)/(((RHEIGHT(ELEMENT)/2)*RUND(1))
     *                                +(RHEIGHT(ELEMENT)/4))

                 IF (RANGE .LT. .250) THEN
                         BLUEPDET=1.0
                        GO TO 14
                 END IF

                      DENOM=1.453+(TAU*(.05978+(2.188*RNGAPP*RNGAPP)))

                      DETRATE=.75*(-.003+(1.088/DENOM))

                  IF (DETRATE .LE. 0.0) THEN
                   DETRATE = 0.0
                  ELSE IF (DETRATE .GT. 5.0) THEN
                   BLUEPDET=1.0
                   GO TO 14
                  END IF

                      BLUEPDET=1-EXP(-DETRATE*30)
 14        IF (BLUEENGAGE(ELEMENT) .GE. 4) THEN
                     GO TO 29
                   END IF

             IF (BLUEPDET .GE. RUND(2)) THEN
                  IF (RANGE .LE. BLUERMAX(UNIT,POSITION)) THEN

              RNGADJ=(RANGE/(.25+(RUND(3)/4)) + RRAF(RVEHTYP(ELEMENT)))

              IF (RNGADJ .LT. RNGDET(UNIT,POSITION)) THEN
                         RNGDET(UNIT,POSITION) = RNGADJ
                          RANGE1=RANGE
                           BLUESTATUS(UNIT,POSITION) = 2
                   BLUEDETECT1(UNIT,POSITION)=ELEMENT
              END IF
              END IF
             END IF


 29        CONTINUE
             IF (RNGDET(UNIT,POSITION) .LT. 200.0) THEN
           BLUEENGAGE(BLUEDETECT1(UNIT,POSITION))=
     *                 BLUEENGAGE(BLUEDETECT1(UNIT,POSITION))+1

             END IF

              RETURN
                END
*******************************************************************
```

```
******************   FIRE   ***********************************

      SUBROUTINE REDFIRE(REDSTATUS,ELEMENT,REDENGAGE,BLUESTATUS,UNIT,
     *            POSITION,NUMBLUE,REDXPOS,REDYPOS,NUNIT,VEHTYPE,
     *            REDDETECT1,REDDETECT2,BLUEX1POS,BLUEY1POS,DSEED,
     *            CLOCK,RVEHTYP,RPHITS,RPHITM,RPKILL,DFKILL,REP,DFTYPE)
      INTEGER REDSTATUS,ELEMENT,REDENGAGE,BLUESTATUS,UNIT,POSITION
      INTEGER NUMBLUE,SHOT,REDDETECT1,REDDETECT2,LOOP,NUNIT,RVEHTYP
      INTEGER VEHTYPE,DFKILL,REP,DFTYPE
      REAL RANGE,REDXPOS,REDYPOS,BLUEX1POS,BLUEY1POS
      REAL PHIT,PKILL,RNDNUM,CLOCK,RPHITS,RPHITM,RPKILL
      REAL*8 DSEED
      DIMENSION REDSTATUS(30),REDENGAGE(100),REDXPOS(30),DFKILL(100)
      DIMENSION REDDETECT1(30),REDDETECT2(30),REDYPOS(30),VEHTYPE(10,20)
      DIMENSION BLUESTATUS(10,20),BLUEX1POS(10,20),BLUEY1POS(10,20)
      DIMENSION RNDNUM(10),RVEHTYP(30),RPHITS(10),RPHITM(10),RPKILL(10)
      DIMENSION DFTYPE(10)

         REDSTATUS(ELEMENT)=1

         SHOT=REDDETECT1(ELEMENT)
            LOOP = 1
             GO TO 67

 97      SHOT = REDDETECT2(ELEMENT)
             LOOP = 2

 67         IF (SHOT .EQ. 0) THEN
                GO TO 87
            ELSE IF (SHOT .GT. 0) THEN
              DO 27 I=1,NUNIT
                 IF (SHOT .LE. I*NUMBLUE) THEN
                UNIT = I
                POSITION = SHOT - ((UNIT-1)*NUMBLUE)
                GO TO 88
                 END IF
 27           CONTINUE
            END IF
 88    RANGE=(SQRT(((REDXPOS(ELEMENT)-BLUEX1POS(UNIT,POSITION))**2)+
     *         ((REDYPOS(ELEMENT)-BLUEY1POS(UNIT,POSITION))**2)))/10

       IF (RVEHTYP(ELEMENT) .EQ. 2) THEN
          IF(RANGE .LT. .250) THEN
              PHIT = RPHITM(5)
              PKILL = RPKILL(5)
           ELSE IF (RANGE .LT. 1.000) THEN
              PHIT = RPHITM(6)
              PKILL = RPKILL(6)
           ELSE IF (RANGE .LT. 1.500) THEN
              PHIT = RPHITM(7)
              PKILL = RPKILL(7)
           ELSE IF (RANGE .LT. 2.500) THEN
              PHIT = RPHITM(8)
              PKILL = RPKILL(8)
           ELSE IF (RANGE .LT. 4.400) THEN
              PHIT = RPHITM(9)
              PKILL = RPKILL(9)
           END IF
          GO TO 76
          END IF

          IF(RANGE .LT. .500) THEN
```

```
                 PHIT = RPHITM(1)
                 PKILL = RPKILL(1)
              ELSE IF (RANGE .LT. 1.000) THEN
                 PHIT = RPHITM(2)
                 PKILL = RPKILL(2)
              ELSE IF (RANGE .LT. 2.000) THEN
                 PHIT = RPHITM(3)
                 PKILL = RPKILL(3)
              ELSE IF (RANGE .LT. 3.300) THEN
                 PHIT = RPHITM(4)
                 PKILL = RPKILL(4)
              END IF
 76         CALL GGUBS(DSEED,2,RNDNUM)
              IF (BLUESTATUS(UNIT,POSITION) .EQ. 0) GO TO 87
                  IF (RNDNUM(1) .LE. PHIT) THEN
                        IF (RNDNUM(2) .LE. PKILL) THEN
                             BLUESTATUS(UNIT,POSITION) = 0
                             DFKILL(REP)=DFKILL(REP)+1
            DFTYPE(VEHTYPE(UNIT,POSITION))=DFTYPE(VEHTYPE(UNIT,POSITION))+1
                         REDENGAGE((NUMBLUE*(UNIT-1))+POSITION) = 2
       WRITE(54,747) CLOCK,ELEMENT,RANGE,UNIT,POSITION,
     *                VEHTYPE(UNIT,POSITION)
 747   FORMAT(1X,F5.1,' RED ',I2,' RANGE ',F6.3,
     *    ' KILLED BLUE',2I3,' VEHTYPE ',I2,' BBBBBBBBBBB')
                              GO TO 87
                          END IF
                  END IF

            REDENGAGE((NUMBLUE*(UNIT-1))+POSITION) =
     *              REDENGAGE((NUMBLUE*(UNIT-1))+POSITION) - 1

 87       IF (LOOP .EQ. 1) THEN
            GO TO 97
          END IF
                RETURN
                 END
*****************************************************************


       SUBROUTINE BLUEFIRE(REDSTATUS,ELEMENT,BLUEENGAGE,BLUESTATUS,UNIT,
     *             POSITION,REDXPOS,REDYPOS,RVEHTYP,
     *             BLUEDETECT1,BLUEX1POS,BLUEY1POS,DSEED,
     *             CLOCK,BPHITS,BPKILL)
       INTEGER REDSTATUS,ELEMENT,BLUEENGAGE,BLUESTATUS,UNIT,POSITION
       INTEGER BLUEDETECT1,RVEHTYP
       REAL RANGE,REDXPOS,REDYPOS,BLUEX1POS,BLUEY1POS
       REAL PHIT,PKILL,RNDNUB,CLOCK,BPHITS,BPKILL
       REAL*8 DSEED
       DIMENSION REDSTATUS(30),BLUEENGAGE(30),REDXPOS(30)
       DIMENSION BLUEDETECT1(10,20),REDYPOS(30)
       DIMENSION BLUESTATUS(10,20),BLUEX1POS(10,20),BLUEY1POS(10,20)
       DIMENSION RNDNUB(10),RVEHTYP(30),BPHITS(10),BPKILL(10)

          BLUESTATUS(UNIT,POSITION)=1
          ELEMENT=BLUEDETECT1(UNIT,POSITION)
        RANGE=(SQRT(((REDXPOS(ELEMENT)-BLUEX1POS(UNIT,POSITION))**2)+
     *             ((REDYPOS(ELEMENT)-BLUEY1POS(UNIT,POSITION))**2)))/10

         IF (RVEHTYP(ELEMENT) .EQ. 2) THEN
           IF(RANGE .LT. .500) THEN
```

```
                  PHIT = BPHITS(5)
                  PKILL = BPKILL(5)
               ELSE IF (RANGE .LT. 1.000) THEN
                  PHIT = BPHITS(6)
                  PKILL = BPKILL(6)
               ELSE IF (RANGE .LT. 2.000) THEN
                  PHIT = BPHITS(7)
                  PKILL = BPKILL(7)
               ELSE IF (RANGE .LT. 3.300) THEN
                  PHIT = BPHITS(8)
                  PKILL = BPKILL(8)
               END IF
           GO TO 74
             END IF

              IF(RANGE .LT. .500) THEN
                  PHIT = BPHITS(1)
                  PKILL = BPKILL(1)
               ELSE IF (RANGE .LT. 1.000) THEN
                  PHIT = BPHITS(2)
                  PKILL = BPKILL(2)
               ELSE IF (RANGE .LT. 2.000) THEN
                  PHIT = BPHITS(3)
                  PKILL = BPKILL(3)
               ELSE IF (RANGE .LT. 3.300) THEN
                  PHIT = BPHITS(4)
                  PKILL = BPKILL(4)
               END IF

74           CALL GGUBS(DSEED,2,RNDNUB)
                IF (REDSTATUS(ELEMENT) .EQ. 0) GO TO 83
                   IF (RNDNUB(1) .LE. PHIT) THEN
                         IF (RNDNUB(2) .LE. PKILL) THEN
                              REDSTATUS(ELEMENT) = 0
                         BLUEENGAGE(ELEMENT) = 4
          WRITE(54,777) CLOCK,UNIT,POSITION,RANGE,ELEMENT
777       FORMAT(1X,F5.1,' BLUE ',2I4,' AT RANGE ',F6.3,' KILLED RED ',I3,
         *             ' RRRRRRRRRRRRRRRR')
                               GO TO 83
                           END IF
                   END IF

               BLUEENGAGE(ELEMENT) = BLUEENGAGE(ELEMENT)-1


83                RETURN
                   END
  ******************************************************************
```

APPENDIX C

DATA FILES TO SUPPORT THE PROGRAM

This appendix contains the data files used in the program listed in Appendix B. Most data files can be expanded or reduced as long as the appropriate parameters are changed in the program.

The network is supported by the MINEMET data file shown below. The first column is the arc number, the second column is the node number of the tail of the arc while the third column is the node number of the head of the arc. The fourth column is the distance associated with the arc while the last column is the heading of the arc in radians.

1	1	2	2.92	5.616
2	1	3	3.13	5.989
3	2	13	1.44	5.692
4	3	4	0.67	1.107
5	3	5	1.25	0.499
6	4	7	1.86	0.633
7	5	6	0.54	0.381
8	7	8	0.41	6.141
9	6	9	0.48	0.322
10	8	11	1.26	6.141
11	9	10	0.92	6.056
12	10	22	1.23	6.064
13	11	12	1.00	6.141
14	12	26	0.61	0.000
15	13	14	0.92	6.064
16	14	19	1.84	0.704
17	19	20	0.81	0.704
18	14	15	0.92	5.865
19	15	16	0.70	6.005
20	16	17	0.62	0.464
21	17	18	0.71	1.373
22	18	23	0.76	0.785
23	23	24	0.71	0.785
24	24	25	0.99	0.785
25	20	21	0.64	0.675
26	21	22	0.99	0.644
27	22	26	0.54	0.927
28	25	26	0.82	1.816
29	26	27	0.70	5.819
30	27	28	0.53	0.927
31	28	29	0.00	0.000

The NODLOC file is the physical location of each node in the network. The first column is the node, the second is the x coordinate while the third is the y coordinate. If the x and y coordinate were put together they would represent the standard six digit grid coordinate system.

1	583	229
2	606	211
3	613	220
4	616	226
5	624	226
6	635	230
7	631	237
8	635	236
9	639	231
10	648	229
11	647	232
12	657	232
13	618	203
14	627	201
15	636	197
16	643	195
17	649	198
18	650	205
19	640	214
20	647	218
21	652	222
22	660	228
23	653	212
24	658	217
25	665	224
26	663	232
27	669	229
28	672	233
29	672	233

The Avenue Data is used to support the Movement network. Each value is an arc number, with each avenue represented by a column of arcs. The last arc in the network, arc 31 is an arc with no speed associated with it, so if a unit reaches that arc (which is past the objective) it would essentially remain in position unitl the arrival of the rest of the units.

2	2	1	1
4	5	3	3
6	7	15	15
8	9	16	18
10	11	17	19
13	12	25	20
14	27	26	21
29	29	27	22
30	30	29	23
31	31	30	24
31	31	31	28
31	31	31	29
31	31	31	30

The SPEED file represents the speeds that the various types of equipment in the unit are able to maintain over the various arcs. The speeds are affected by terrain, roads, cities and other natural objects such as forests. The columns in order represent an M1, a mineplow tank with the plow in the raised position, a mineroller tank with the rollers in the position, a mineplow tank with the plow employed, and finally the mineroller tank in the breaching mode.
raised position, a mineroller tank with the roller

27	21	16	9	12
27	21	16	9	12
27	21	16	9	12
20	13	10	9	8
24	19	13	8	10
27	21	16	9	12
24	19	13	8	10
27	21	16	9	12
27	21	16	9	12
27	21	16	9	12
27	21	16	9	12
27	21	16	9	12
20	13	10	9	8
13	8	7	4	5
27	21	16	9	12
27	21	16	9	12
27	21	16	9	12
27	21	16	9	12
27	21	16	9	12
33	26	19	9	12
33	26	19	9	12
27	21	16	9	12
27	21	16	9	12
27	21	16	9	12
27	21	16	9	12
27	21	16	9	12
17	11	8	5	7
27	21	16	9	12
27	21	16	9	12
40	31	24	9	12
27	21	16	9	12

This file is used to input the type and order of the equipment in each ofthe units. The only three codes used are: 1 for an M1, 2 for a mineplow tank, and three for a mineroller tank. The vehicles can be placed in any order and the units do not have to be configured the same, either in the type of equipment or the order in which it is entered.

```
2  2  2  2
2  2  2  2
3  3  3  3
3  3  3  3
1  1  1  1
1  1  1  1
1  1  1  1
1  1  1  1
1  1  1  1
1  1  1  1
1  1  1  1
1  1  1  1
1  1  1  1
1  1  1  1
```

The following is an example of the file that support the formations. The offsets in the x and y directions are given in hundreds of meters, therefore the value -2.50 would be two hundred and fifty meters in either the minus x direction if it was in the first column or the minus y direction if it was in the second column.

-5.00	.00
-7.00	.00
-6.50	.50
-6.50	-.50
-6.00	.00
-0.50	4.00
-0.50	-4.00
-1.00	-3.50
-0.50	-3.00
-0.50	3.00
-1.00	3.50
.00	.00
.00	-3.50
.00	3.50

The data used in this file represents the blue probability of hitting a target given a range band and then the probability of killing the target given a hit. The first column is the hit probability while the second is the kill probability.

```
X.XX  X.XX
X.XX  X.XX
X.XX  X.XX
X.XX  X.XX
X.XX  X.XX
X.XX  X.XX
X.XX  X.XX
X.XX  X.XX
```

The REDPOSN file represents the physical location of each red element in the unit. The first column is the element number, the secon is the x coordinate, and the third is the y coordinate. If the two coordinates were put together they would represent a standard eight digit grid coordinate.

1	666.5	228.0
2	668.0	228.5
3	665.5	230.0
4	663.5	229.5
5	663.5	230.5
6	662.0	231.5
7	662.0	232.5
8	661.0	235.0
9	661.5	235.0
10	663.5	233.0
11	667.0	229.5
12	665.5	231.0
13	663.5	232.0

The RPLOOK file is used in the red DETECTION subroutine and represents the probability that the observer is looking in the direction of the target, in this case each of the four avenues of approach used by the blue forces. They are user input and the probability of looking in all directions does not have to add to 1.

0.10	0.10	0.35	0.40
0.10	0.10	0.35	0.40
0.10	0.10	0.35	0.40
0.10	0.25	0.40	0.20
0.10	0.25	0.40	0.20
0.10	0.25	0.40	0.20
0.40	0.40	0.10	0.05
0.40	0.40	0.10	0.05
0.40	0.40	0.10	0.05
0.25	0.25	0.25	0.25
0.05	0.10	0.40	0.40
0.05	0.10	0.40	0.40
0.30	0.40	0.15	0.10

The RVEHTYP file supports the red unit in terms of type of equipment, height, range adjustment factor and maximum effective range. The first column is the vehicle type, with a 1 representing a tank, while a 2 represents a BMP. Column 2 is the height of the vehicle while column 3 is the range adjustment factor (RAF) used in the simulation. The RAF represents the range difference that would be required between a tank and a BMP before the the BMP would be engaged. The last column is the maximum effective range of the weapon system.

1	2.3	0	3.0
1	2.3	0	3.0
1	2.3	0	3.0
1	2.3	0	3.0
1	2.3	0	3.0
1	2.3	0	3.0
1	2.3	0	3.0
1	2.3	0	3.0
1	2.3	0	3.0
1	2.3	0	3.0
2	2.1	0.4	4.0
2	2.1	0.4	4.0
2	2.1	0.4	4.0

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